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Field trials of terrestrial multimedia mobile broadcasting systems

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Note*: This ITU-R Report was approved in English by the Study Group under the procedure detailed in Resolution ITU-R 1.*

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REPORT ITU-R BT.2526-2

Field trials of terrestrial multimedia mobile broadcasting systems

(Question ITU-R 132/6)

(2023-2024-2025)

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Scope

This Report collects summary descriptions of trials in different countries of new technologies for terrestrial multimedia broadcasting for mobile reception in the broadcasting bands. As technology for terrestrial multimedia broadcasting for mobile reception is still evolving, new trials will be done, and this Report will be updated accordingly.

Keywords

Broadcasting bands, field trials, mobile reception, terrestrial multimedia broadcasting

Abbreviations/Glossary

1T2R	1 Transmit 2 Receive
4T4R	4 Transmit 4 Receive
AMC	Adaptive modulation and coding
API	Application programming interface
APP	Application
ARFCN	Absolute radio frequency channel number
AWGN	Additive white gaussian noise
BBU	Baseband unit
BLER	Block error rate
BSCC	Broadcast service and control centre
C/I	Carrier-to-interference
C/N	Carrier-to-noise
CAS	Cell acquisition subframe
CBN	China Broadnet
CCTV	China Central Television
CDN	Content delivery networks
CF	Centre frequency
COFDM	Coded orthogonal frequency-division multiplexing
CP	Cyclic prefix
CPU	Central processing unit
CRC	Cyclic redundancy check
DASH	Dynamic adaptive streaming over HTTP
DTTB	Digital terrestrial television broadcasting
eMBMS	LTE evolved multimedia broadcast multicast services
EMF	Electromagnetic field
ERP	Effective radiated power
FeMBMS	LTE further evolved multimedia broadcast multicast service
FLUTE	File delivery over unidirectional transport protocol

G-RNTI	Group radio network temporary identifier
GNSS	Global navigation satellite system
HbbTV	Hybrid broadcast broadband TV
HD	High definition
HE-AACv1	High-efficiency advanced audio coding, version 1
HEVC	High efficiency video coding
HLS	HTTP live streaming
HPHT	High-power-high-tower transmitters
ILS	Internet link service
IoT	Internet of Things
IPv4/IPv6	Internet Protocol version 4/ Internet Protocol version 6
ISD	Inter-site distance
LPLT	Low-power-low-tower
LTE	Long term evolution
MBS	Multicast and broadcast system
MCS	Modulation and coding scheme
MPEG	Moving Pictures Experts Group
NR	New radio
OTT	Over-the-top
PBCH	Physical broadcast channel
PPS	Pulse per second
PNT	Positioning, navigation, and timing
PTN	Packet transport network
PUCCH	Physical uplink control channel
QEF	Quasi error free
QoE	Quality of Experience
QoS	Quality of Service
RAN	Radio access network
RF	Radio frequency
RRU	Remote radio unit
RSRP	Reference signal received power
RTP	Real-time transport protocol
SCS	Subcarrier spacing
SDI	Serial digital interface
SDL	Supplemental down link
SDR	Software defined radio

SFN	Single frequency network
SINR	Signal-to-interference plus noise ratio
SNR	Signal-to-noise ratio
SS_RSRP	SS reference signal received power
SSA	Seamless switching application
SSB	Single-sideband
TMMB	Terrestrial multimedia mobile broadcasting
TOD	Time of day
TOV	Threshold of visibility
TsoIP	Transport stream over IP
TU6	Typical urban scenario
UE	User equipment
USD	User service description
V2X	Vehicle-to-Anything
VDCM	Virtual digital content manager
VR	Virtual reality

1 Introduction

The objective of this Report is to collect summary descriptions of trials of new technologies for terrestrial multimedia broadcasting for mobile reception in the broadcasting bands.

The way in which media content and services are delivered to viewers and listeners is evolving and, in particular, is driven by the rise of the Internet and the popularity of personal devices (smartphones, tablets) to access audiovisual media content and services. With the fast development of mobile Internet services, users are getting used to viewing and generating video anywhere anytime. The existing terrestrial multimedia broadcasting systems, with main attribute of downlink-only and large/static transmission areas, have not been integrated widely into mobile devices. New multimedia broadcasting technologies, integrated with mobile technologies, have been standardized in 3GPP, and are still evolving.

Apart from the video applications, other services can be offered by these new terrestrial broadcasting multimedia systems. Such services include public safety, V2X (vehicle to anything) communications, IoT software upgrade and others.

To verify the system design and the performance of the new technologies for terrestrial multimedia broadcasting, Broadcast network operators and Research and Development organizations have developed prototype trial systems and in collaboration with Broadcasters, have conducted field experiments with both high-tower deployment and regular base station deployment. Some initial results for relevant experiments were achieved.

The Annexes to this Report collect the field trials information of new technologies for terrestrial multimedia broadcasting systems by different operators and in different countries. It is important to note that the trials and projects featured in this Report constitute a snapshot in time. More trials and eventually deployment of commercial networks can be expected in the times to come. This Report is updated as required to reflect the ongoing developments.

The names used for the terrestrial multimedia broadcasting systems subject to trials reported in the present document correspond to the ITU adopted names for Terrestrial multimedia mobile broadcasting (TMMB) systems in Recommendation ITU-R BT.2016, as follows:

System name used in this Report	System name adopted in ITU
LTE-based 5G terrestrial broadcast	TMMB System L
5G NR MBS	TMMB System N
ATSC 3.0	TMMB System S

2 Status of standardization of terrestrial multimedia mobile broadcasting systems

2.1 Status of standardization of the LTE-based 5G terrestrial broadcast system

2.1.1 Recommendations and Reports within ITU

The specification of parameters for LTE-based 5G terrestrial broadcast system has been completed in ITU-R and different Recommendations and Reports have already been published, for example:

– Recommendation ITU-R BT.1833 – Broadcasting of multimedia and data applications for mobile reception by handheld receivers
– Recommendation ITU-R BT.2016 – Error-correction, data framing, modulation and emission methods for terrestrial multimedia broadcasting for mobile reception using handheld receivers in VHF/UHF bands
– Report ITU-R BT.2049 – Broadcasting of multimedia and data applications for mobile reception
– Report ITU-R BT.2295 – Digital terrestrial broadcasting systems.

2.1.2 Standardization within 3GPP

The LTE-based 5G Terrestrial Broadcast system is standardised in 3GPP Release 16.

Further normative work has been completed, with the addition of 6/7/8 MHz bandwidths in Release 17. This has subsequently been profiled as ETSI TS 103 720 [1].

2.2 Status of standardization of 5G new radio multicast and broadcast system

2.2.1 Recommendations and Reports within ITU

The specification of parameters for 5G new radio (NR) multicast and broadcast system (MBS) has been completed in ITU-R and different Recommendations and Reports have been published, for example:

– Recommendation ITU-R BT.1833 – Broadcasting of multimedia and data applications for mobile reception by handheld receivers
– Recommendation ITU-R BT.2016 – Error-correction, data framing, modulation and emission methods for terrestrial multimedia broadcasting for mobile reception using handheld receivers in VHF/UHF bands
– Report ITU-R BT.2049 – Broadcasting of multimedia and data applications for mobile reception
– Report ITU-R BT.2295 – Digital terrestrial broadcasting systems.

2.2.2 Standardization within 3GPP

The standardization of parameters for 5G NR MBS is underway at 3GPP, for example:

– 5G NR MBS is one of the major focuses of 3GPP in Release 17, and a number of new study items and work items were approved in Release-17 targeting to make NR support of multicast and broadcast and to offer efficient support of services like public safety, mission critical communications, V2X applications, transparent IPv4/IPv6 multicast delivery, IPTV, and software delivery over wireless networks.

2.3 Status of standardization of ATSC 3.0

2.3.1 Recommendations and Reports within ITU

The specification of parameters for ATSC 3.0 terrestrial broadcast system has been completed in ITU-R and different Recommendations and Reports have already been published, for example:

– Recommendation ITU-R BT.1833 – Broadcasting of multimedia and data applications for mobile reception by handheld receivers

– Recommendation ITU-R BT.2016 – Error-correction, data framing, modulation and emission methods for terrestrial multimedia broadcasting for mobile reception using handheld receivers in VHF/UHF bands

– Report ITU-R BT.2049 – Broadcasting of multimedia and data applications for mobile reception

– Report ITU-R BT.2295 – Digital terrestrial broadcasting systems.

2.3.2 Standardization within ATSC

The standardization of parameters for ATSC 3.0 terrestrial broadcast system has been completed in ATSC and several Standards have already been published, for example:

– ATSC Standard A/300 – *ATSC 3.0 System*

– ATSC Standard A/321 – *System Discovery and Signalling*

– ATSC Standard A/322 – *Physical Layer Protocol.*

3 Initiatives to promote trials and implementation of multimedia broadcasting systems

5G-Media Action Group (5G-MAG)

5G-Media Action Group (5G-MAG) provides a framework to collaborate on a market-driven implementation of technologies for the connected media world. In particular, those in the domain of 5G applied to content creation, production, distribution and consumption. 5G-MAG is a cross-industry, non-profit, association that gathers content and service providers, network operators, technology solution suppliers, software developers, equipment manufacturers, R&D organizations, universities, regulators or policy makers.

5G-MAG develops open-source tools that support 5G-based media distribution (https://www.5g-mag.com/reference-tools). These tools implement specifications and so allow for testing and for use in trials and in production. 5G-MAG also promotes and reports on trials and demonstrations (https://www.5g-mag.com/trials).

4 Field trials of terrestrial multimedia mobile broadcasting systems

The Annexes show details of trials conducted for new terrestrial multimedia broadcasting systems in different countries.

As this report deals with evolving technologies, the implementation and the performance of the receiving and transmitting equipment can be improved in the future.

The following Table summarizes the trials and indexes the Annexes.

Summary of trials of terrestrial multimedia mobile broadcasting systems

Annex/Section	Country	Cities	Trial name	TMMB system (Note)	Frequency range used	Date
Annex 1/§ 1	China	Beijing, Shanghai	5G NR MBS Trial in Beijing and in Shanghai	5G NR MBS	758-768 MHz	October 2020/ November 2021
Annex 1/§ 2		Nanjing	5G NR MBS Trial in Nanjing	5G NR MBS	Within the 700 MHz range	October 2021
Annex 1/§ 3		Beijing	HPHT and LPLT 5G NR MBS cooperative networking test	5G NR MBS	Within the 700 MHz range	May 2023
Annex 1/§ 4		Laboratory tests	Laboratory testing of 5G NR systems in the 700 MHz band	5G NR MBS	Within the 700 MHz range	January 2023
Annex 1/§ 5		Shenzhen	The Test Report of the Wireless Digital Multimedia Broadcasting Network	LTE-based 5G Terrestrial Broadcast	682 MHz	August 2022
Annex 1/§ 6		Beijing	5G NR MBS Network Planning and Trial	5G NR MBS	Within the 700 MHz range	December 2023
Annex 1/§ 7		Beijing	Multimedia service trials based on 5G NR MBS in Beijing	5G NR MBS	Within the 700 MHz range	July 2024
Annex 1/§ 8		Wuhan	The 5G NR MBS trial in Wuhan	5G NR MBS	Within the 700 MHz range	November 2024
Annex 1/§ 9		Anhui	The 5G NR MBS trial in Anhui	5G NR MBS	Within the 700 MHz range	December 2024
2	Switzerland France Germany Italy Austria	Geneva Paris Stuttgart Turin Vienna	LTE-based 5G broadcast of the Eurovision Song Contest 2022	LTE-based 5G Terrestrial Broadcast	600 MHz range 219.5 MHz (VHF ch. 11 used in Turin only)	April/May 2022 October 2021
Annex 3/§ 1	Germany	Stuttgart, Heilbronn	5G Media2Go	LTE-based 5G Terrestrial Broadcast LTE Unicast	622-630 MHz	October 2020/ September 2022
Annex 3/§ 2		Hamburg	LTE-based 5G broadcast in Hamburg	LTE-based 5G Terrestrial Broadcast	622-630 MHz	October 2021/ mid 2026

Annex/Section	Country	Cities	Trial name	TMMB system (Note)	Frequency range used	Date
Annex 3/§ 3		Halle	LTE-based 5G broadcast in Halle	LTE-based 5G Terrestrial Broadcast	622-630 MHz	Started June 2024
Annex 3/§ 2		Hamburg	LTE-based 5G broadcast in Hamburg	LTE-based 5G Terrestrial Broadcast	574-582 MHz	October 2021/ December 2023
4	Austria	Vienna	Vienna field trials	LTE-based 5G Terrestrial Broadcast	734-744 MHz 662-672 MHz 638-642 MHz	2020/2021 – Phase 1 2021/2023 – Phase 2
5/§ 1	Italy	Aosta Valley	LTE-based 5G broadcast trial in Aosta Valley	LTE-based 5G terrestrial broadcast	726-734 MHz	November 2021/ June 2022
5/§ 2		Turin and Palermo	Rai Way Trial of LTE-based 5G broadcast network and services in the 700 MHz band in the cities of Turin and Palermo	LTE-based 5G terrestrial broadcast and seamless switching broadband/broadcast	743-748 MHz (SDL-B2)	July 2022/July 2023
5/§ 3		Lissone (Monza-Brianza)	EI-Towers LTE-based 5G broadcast field Trial in Lissone (Monza-Brianza)	LTE-based 5G terrestrial broadcast	738-743 MHz (SDL-B1)	March 2023
5/§ 4		Milano and Palermo	EI-Towers LTE-based 5G Broadcast trial of a broad SFN coverage in the Milan and Palermo Area	LTE-based 5G terrestrial broadcast	738-743 MHz (SDL-B1) 743-748 MHz (SDL-B2)	August 2023/November 2024
5/§ 5		Rome and Turin	LTE-based 5G Broadcast pre-commercial service and trials in major Italian cities (2024/2025)	3GPP Rel. 16 5G Broadcast feature set on top of 3GPP Rel. 12 eMBMS (release currently available in commercial smartphone)	614-654 MHz	Started in November 2024
6	Denmark	Copenhagen	LTE-based 5G Terrestrial Broadcast field trials in Denmark	LTE-based 5G terrestrial broadcast	617-622 MHz	June – July 2022
7	Spain	Barcelona	LTE-based 5G Broadcast trial during MWC in 2020, 2022 and 2023	FeMBMS LTE-based 5G terrestrial broadcast and eMBMS	750-755 MHz 617-627 MHz 617-622 MHz	February 2020 February 2022 February 2023
8	France	Paris	LTE-based 5G Broadcast trial during the Roland-Garros tennis tournament 2023	LTE-based 5G terrestrial broadcast	630-638 MHz	May-June 2023

Annex/Section	Country	Cities	Trial name	TMMB system (Note)	Frequency range used	Date
9	Korea (Republic of)	North area of Gyeonggi province	Performance evaluation of LTE-based 5G Broadcast	LTE-based 5G terrestrial broadcast	765-771 MHz	July 2023
10	Korea (Republic of)	North area of Gyeonggi province	Performance Evaluation of ATSC 3.0	ATSC 3.0	765-771 MHz	July 2023
11	France	Paris Nantes Bordeaux	LTE-based 5G Broadcast trial during the 2024 Olympic and Paralympic Games	LTE-based 5G terrestrial broadcast	617-622 MHz 620-630 MHz 632-637 MHz	April-September 2024
12/§ 1	Korea (Republic of)	Seoul and Metropolitan Area	Performance Evaluation of ATSC 3.0 with Diversity Receiver	ATSC 3.0	765-771 MHz	September-October 2024
12/§ 2		Seoul and metropolitan area	Performance evaluation of ATSC 3.0 diversity reception with different antenna types	ATSC 3.0	765-771 MHz	September 2024
13	Czech Republic	Prague	LTE-based 5G Broadcast in Prague	LTE-based 5G terrestrial broadcast	742-750 MHz	April 2022 (Phase 1) May/July 2023 and continued in 2024 (Phase 2)

Note: For further information about the exact version or release of the system standard see the corresponding Annex in this Report.

5 References

[1] ETSI TS 103 720 V1.2.1 (2023-06), "5G Broadcast System for linear TV and radio services; LTE-based 5G terrestrial broadcast system"
https://www.etsi.org/deliver/etsi_ts/103700_103799/103720/01.02.01_60/ts_103720v010201p.pdf

Annex 1

Field trials of 5G new radio multicast and broadcast system (5G NR MBS) and of LTE-based 5G terrestrial broadcast in China

1 The 5G NR MBS trial in Beijing and in Shanghai

1.1 Background

To verify the system design and the performance of 5G NR MBS, China Broadnet (CBN) has developed a prototype trial system following the design principal of 5G NR MBS. Field experiments were conducted in Beijing, with both high-tower deployment and regular base station deployment. This paper provides some initial results for relevant experiments.

1.2 Initial experimental results for 5G NR MBS with high-tower deployment

As illustrated in Fig. 1, regular 5G base station is deployed on the centre radio and TV tower, 200 metres above the ground. Directional antennas are used for the base station, with one antenna pointing the east and another antenna pointing the south. Detailed parameters for the test setup are listed in Table 1.

TABLE 1

Test setup for 5G NR MBS

Testing frequency range	758-768 MHz
Carrier bandwidth	10 MHz
Base station transmission power	240 Watts (4 × 60 Watts)
modulation mode	QPSK
MCS	4
Rank	1
Base station height	207 m
Antenna direction	90 degrees (due east), 180 degrees (due south)
Antenna dip angle	2 degrees
Device	Huawei Mate 30 pro

TABLE 1 (*end*)

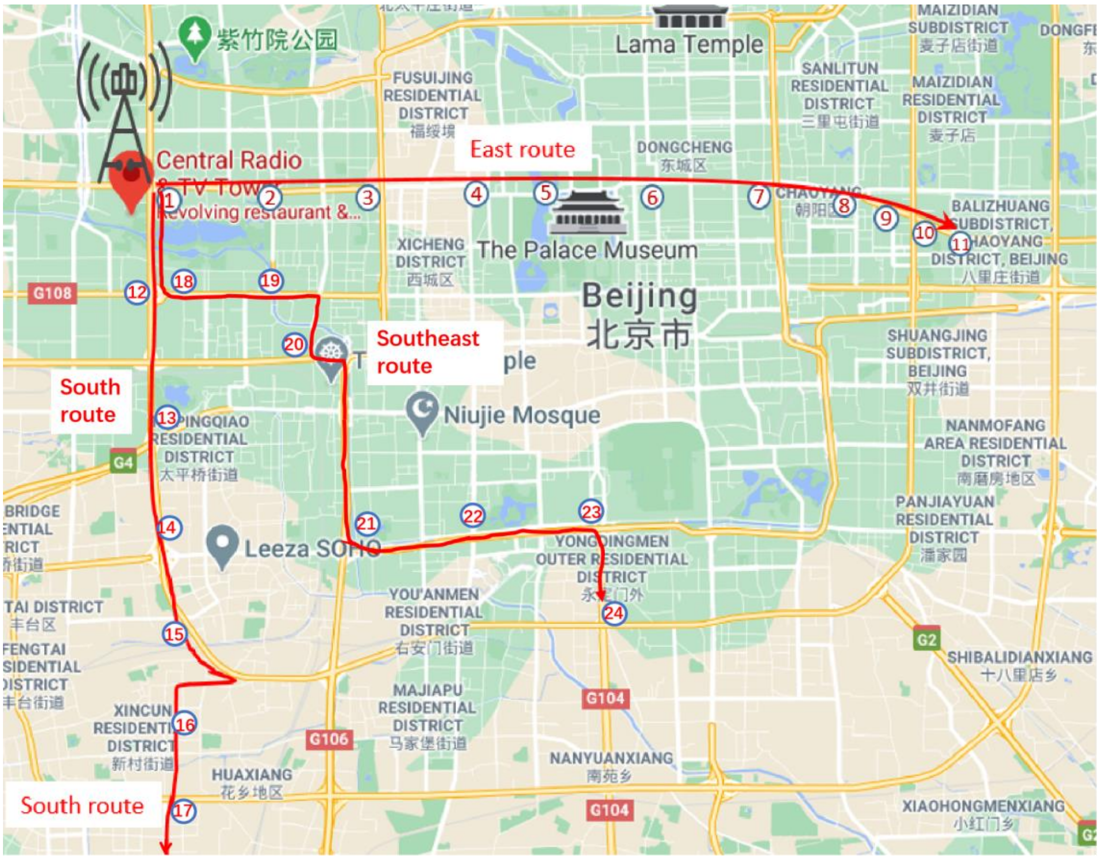
Receiving device location	In the car
Receiving device height	1 m
Receiving conditions	On-board road test in the car, hand-hold
Testing date	From October 2020 to January 2021

NOTE – This NR MBS experiment based on high-tower deployment is in Read Only Mode, data transmission on receiving devices is downlink-only.

There are three routes tested. The east route represents typical urban scenario with dense buildings and high buildings. For the south route, it includes high-speed freeway and sub-urban scenario. And for the southeast route, it includes high-speed freeway and urban scenario. Four test devices receive the same video broadcast services from the base station.

FIGURE 1

Field experiments for 5G NR MBS



Initial test results show that test devices can receive video broadcast service with good quality from more than 10 km away from the central radio and TV tower for east route and south route as well as southeast route. Due to speed limitation in the city, the highest speed tested is 80 km/h. For such relatively high-speed scenario, no performance degradation was observed. The test adopts 10 MHz channel bandwidth. Testing video format is 576 × 720, 1 Mbit/s bitrate[1], and H.264 encoding profile. Detailed test results can be found in Tables 2 to 4.

[1] The testing video uses around 1.66 MHz, MCS = 4.

TABLE 2

Test results for east route

Test point	SSB RSRP (Reference signal received power) (dBm)	Distance from base station (km)	Video experience
1	−87	0.636	smooth
2	−86	2.2	smooth
3	−91	4.2	smooth
4	−112	6.0	smooth
5	−97	7.1	smooth
6	−102	8.8	smooth
7	−103	10.8	smooth
8	−115	12.1	smooth
9	−113	12.7	stalling
10	−119	13.2	stalling
11	−117	13.7	stopped

TABLE 3

Test results for south route

Test point	SSB RSRP (Reference signal received power) (dBm)	Distance from base station (km)	Video experience
12	−85	1.3	smooth
13	−103	3.8	smooth
14	−93	5.8	smooth
15	−106	7.7	stalling
16	−107	8.4	stopped
17	−116	9.5	stopped

TABLE 4

Test results for southeast route

Test point	SSB RSRP (Reference signal received power) (dBm)	Distance from base station (km)	Video experience
18	−89	1.3	smooth
19	−100	2.8	smooth
20	−103	3.9	smooth

TABLE 4 (*end*)

Test point	SSB RSRP (Reference signal received power) (dBm)	Distance from base station (km)	Video experience
21	−104	4.4	smooth
22	−106	6.7	stalling
23	−107	8.7	stalling
24	−111	9.8	stopped

The 5G NR MBS video experiments (Fig. 2) based on cellular base station have proved that under R17 NR MBS architecture we can realize the dynamic switch between unicast/multicast/broadcast on a regular 5G cell phone.

FIGURE 2

Video experiments on 5G NR MBS

The experiments reveal that regular 5G base station can be deployed on radio and TV towers and efficiently provide multicast and broadcast video services. And NR MBS based on regular cellular 5G base station can provide dynamic switching between unicast/multicast/broadcast on regular 5G devices. As the experimental test is based on the hardware of commercial devices, it also proves that 5G NR MBS does not require extensive change of 5G NR devices and can hence have short time-to-market.

1.3 Construction of 5G NR MBS trial station on TV tower in Shanghai

On 6 August 2021, CBN completed the construction of 5G NR MBS trial station on the Oriental Pearl TV Tower in Shanghai (shown as Fig. 3), in accordance with the CBN 5G NR MBS promotion plan after the trial testing conducted in Beijing in Q1, 2021. This trial station is based on a commercial 5G NR cellular station which installed 5G NR MBS software working on 700 MHz spectrum, the antenna is mounted on the tower at the height of approximately 320 metres. The expected signal coverage is around 15 km within the tower. Some trials are shown as Fig. 4 and Fig. 5.

In the next stage, CBN will verify the technical feasibility of the 5G NR MBS in various scenarios based on the TV tower deployment in Shanghai. Live TV streaming services/emergency broadcasting services/ultra-high-definition live broadcast, etc. will be tested, and relevant technical preparations will be made for the large-scale commercial deployment of 5G NR MBS services in China.

FIGURE 3

Trial station on Oriental Pearl TV Tower in Shanghai

FIGURE 4

5G NR MBS demo on regular 5G cell phone

FIGURE 5

Panoramic video playback based on 5G cell phone

1.4 5G NR MBS capability verification in commercial scenario

In November 2021, based on 5G NR MBS, CBN completed the verification of new broadcasting services such as multi-angle viewing and panoramic VR video live broadcasting in the Beijing Winter Olympics test events. This is the world's first system capability verification of 5G NR MBS in commercial scenarios, which is of great significance to the subsequent acceleration of the industry chain maturity and full-scenario business innovation.

With 5G NR MBS, audiences in the stadium can freely choose to watch live content such as multi-angle and VR panoramas on 5G terminals including mobile phones and VR wearable devices (shown as Figs 6 to 8), without video jams caused by high concurrency. 5G NR MBS realizes the high-concurrency transmission of high-bitrate multimedia content on consumer mobile phones, which cannot be achieved by traditional broadcasting technologies. The 5G NR MBS deployment integrating VR/XR and other new multimedia formats will create innovative services for broadcasting industry.

In the next stage, CBN will not only innovate and upgrade traditional broadcasting service, but also expand other new multimedia communication services in To-Customer/To-Business, such as integrated high-tech media live broadcast, live broadcast of popular Internet content, Internet of Vehicles, Internet of Things through free switching between multicast and broadcast modes.

Relevant information will be presented in on-line meeting.

FIGURE 6

The ice hockey test field at Beijing Wukesong Stadium

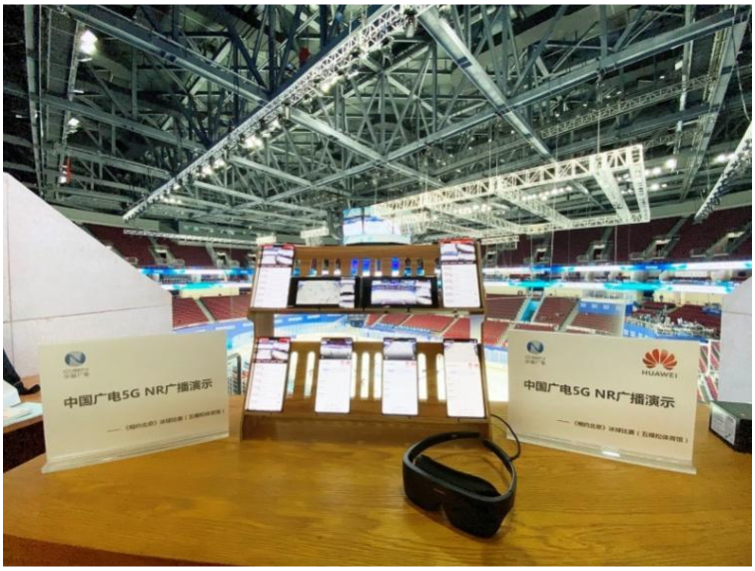


FIGURE 7

Live content such as multi-angle and VR panoramas on 5G terminals including mobile phones and VR wearable devices

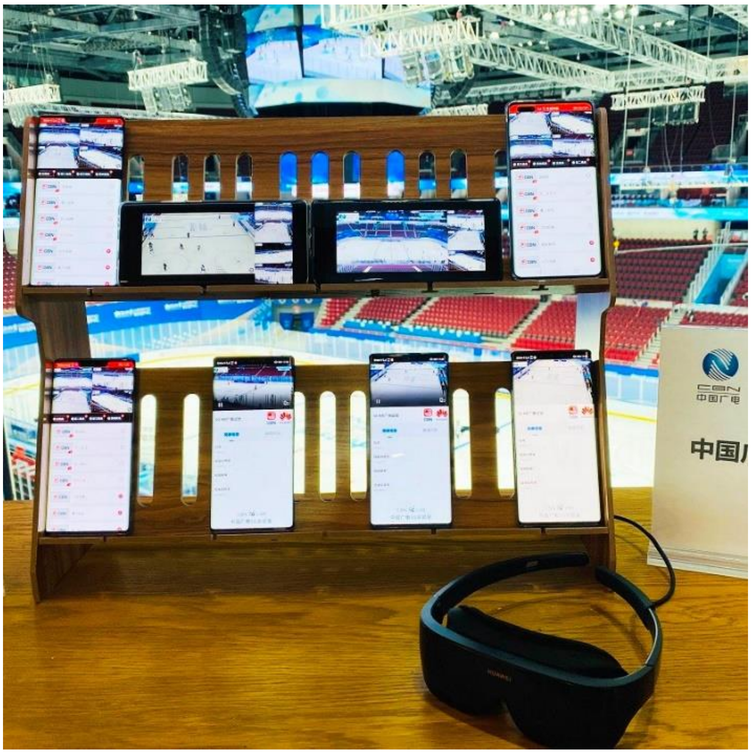
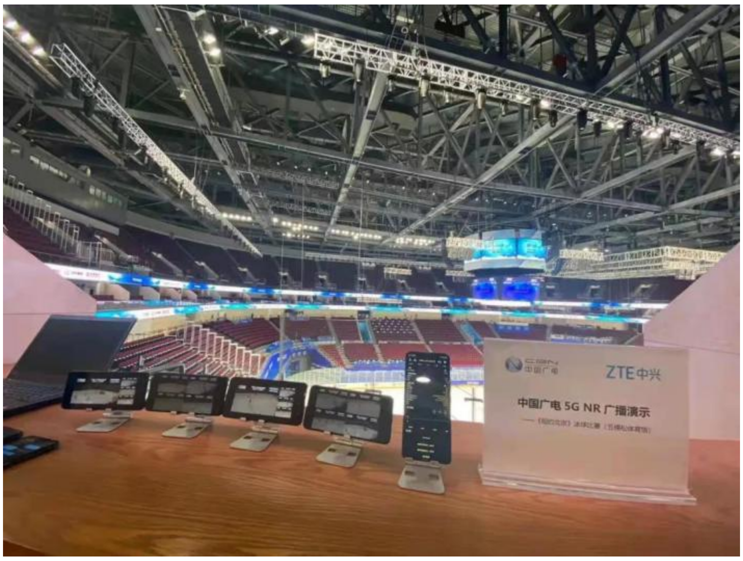


FIGURE 8

Panoramic video playback based on 5G mobile phones



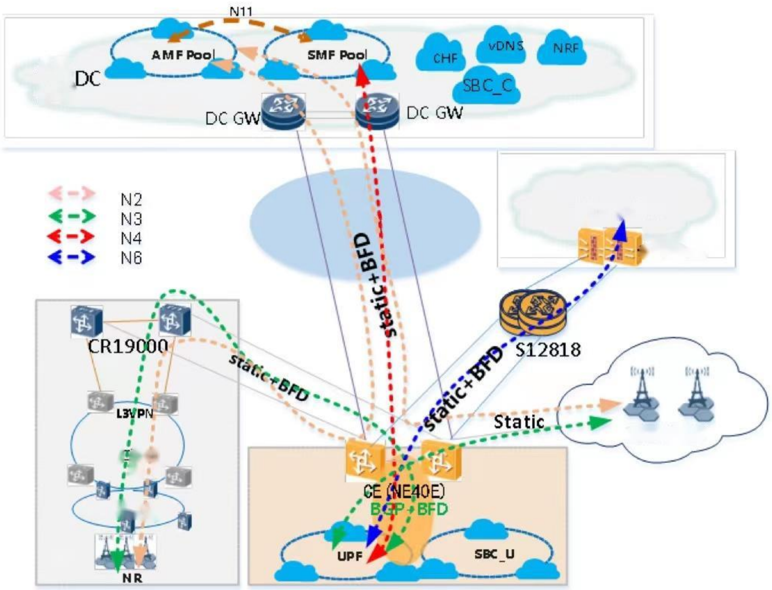
2 The 5G NR MBS trial in Nanjing

2.1 General network architecture

In order to test and verify the performance of 5G NR MBS and explore commercial application experience, CBN conducted a 5G NR MBS trial in Nanjing, Jiangsu Province of China in October 2021. The block diagram of the trial system is shown in Fig. 9.

FIGURE 9

Block diagram of Trial System



2.1.1 Base station parameters

Two base stations were used during the test, the large tower base station (Base station L) and the small tower base station (Base station S), respectively. Base station L is located at the TV tower in Nanjing, Jiangsu Province of China, and Base station S is located at Jiangsu Cable TV industry park in Nanjing, Jiangsu Province of China. Figure 10 shows the Nanjing TV Tower.

FIGURE 10

Nanjing TV Tower

2.1.2 Base station configuration

The two base stations used in the test were built as the outdoor macro base station mode, and the Building Base band Unit (BBU) used during the test is Huawei 5900. The BBU in Base station L was placed in the Jiangsu TV tower service room. The station type was configured as three sectors, and the coverage angle of each sector was 60 degrees.

The BBU of Base station S was placed in the core computer room of the fourth building of Jiangsu Cable TV industry park. The station type was configured as three sectors, and the coverage angle of each sector was set to 120 degrees.

2.1.3 Service streams during the trial

A transcoding system was set up in the TV tower service room, and the video stream was transmitted to the big tower base station and Base station S using fibre optic link, and the information of programme stream was as follows:

1 480P programme stream: H.265 encoding, the bit rate was 1.1 Mbit/s.

2 1080P programme stream: H.265 encoding, the bit rate was 1.5 Mbit/s.

2.1.4 Terminal for the test

During the test, Huawei Mate 40 Pro cell phone (supporting NR MBS version) was used as the test terminal, frequency scanner and road tester were used to help to complete the collection of information.

2.2 Field trial

2.2.1 5G NR MBS coverage test (5 MHz bandwidth)

The purpose of this test is to examine the farthest coverage distance in outdoor open area when 700 MHz base station is configured with 5 MHz bandwidth. The base station used during the test was Base station L.

Shown as Fig. 11, during the test, the test cell phone 1 was placed inside the test vehicle at about 1.5 m above the ground, and was set to play the received broadcast video. Test cell phone 2 was placed next to cell phone 1 and ran the monitoring tool. The test vehicle started from Base station L and moved away along the radial direction until the farthest point where it can receive normally. Due to the topography of Nanjing, the test was carried out in the directions of northwest, southwest and southeast.

FIGURE 11

Test cells phone in test vehicle

(1) Northwest direction

For the 5G NR MBS, the signal started to stutter when the test vehicle travelled to 8.8 km from the base station, and the signal terminated when it reached 10.3 km from the base station.

For two-way data service, when the test vehicle travelled to 5.5 km from the base station, the test cell phone could not link to the base station.

(2) Southwest direction

For the 5G NR MBS, the signal started to stutter when the test vehicle travelled to 9.7 km from the base station, and the signal terminated when it reached 12.1 km from the base station.

For two-way data service, when the test vehicle travelled to 6.2 km from the base station, the test cell phone could not attach to the base station.

(3) Southeast direction

For the 5G NR MBS, the signal started to stutter when the test vehicle travelled to 11.1 km from the base station, and the signal terminated when it reached 12.5 km from the base station.

For two-way data service, when the test vehicle travelled to 4.5 km from the base station the cell phone could not attach to the base station.

2.2.2 5G NR MBS coverage test (10 MHz Bandwidth)

The purpose of this test is to examine the farthest coverage distance in outdoor open area when 700 MHz base station is configured with 10 MHz bandwidth. The base station used in the test was a large tower base station.

During the test, the test cell phone 1 was placed inside the test vehicle at about 1.5 m above the ground and was set to play the received broadcast video. Test cell phone 2 was placed next to cell phone 1 and ran the monitoring tool. The test vehicle started from Base station L and moved away along the radial direction until the farthest point where it could receive normally. Due to the topography of Nanjing, the test was carried out in the directions of northwest, southwest and southeast.

(1) Northwest direction

For the 5G NR MBS, the signal started to stutter when the test vehicle travelled to 7.9 km from the base station, and the signal terminated when it reached 9.4 km from the base station.

(2) Southwest direction

For the 5G NR MBS, the signal started to stutter when the test vehicle travelled to 8.2 km from the base station, and the signal terminated when it reached 10.7 km from the base station.

(3) Southeast direction

For the 5G NR MBS, the signal started to stutter when the test vehicle travelled to 8.1 km from the base station, and the signal terminated at 9.2 km from the base station.

2.2.3 5G NR MBS mobile performance test

The purpose of this test is to examine the outdoor mobile reception performance of the terminal in the open area under different speed. The base station used in the test was Base station L.

During the test, the test cell phone 1 was placed inside the test vehicle at about 1.5 m above the ground and was set to play the received broadcast video. Test cell phone 2 was placed next to cell phone 1 and ran the monitoring tool. The test vehicle started from the near point of the test cell and pulled away radially at different speeds to record the video playback. Due to the topography of Nanjing, the test was carried out in the directions of northwest, southwest and southeast.

The test results showed that the faster the vehicle travelled in the same test area, the more obvious the video jamming was.

2.2.4 5G NR MBS inter-site switching test

The purpose of this test is to test the scenario of service switching when the terminal moves between different stations. The test was conducted in an open scene with a joint test by Base station L and Base station S. The test receiver used two broadcast cell phones (one of which has a built-in CBN SIM card).

The video stream of Jiangsu City Channel was pushed at Base station L, and the video stream of CCTV was pushed at Base station S. Two steams were set at the same bit rate.

The test vehicle started from the near point of the coverage area of Base station L, moved along the test route to Base station S until the near point of the coverage area of Base station S, and observed the broadcasting service playback of the test terminal.

In the near point of the coverage area of Base station L, the test receiver could properly play the Jiangsu City Channel video. When the test vehicle travelled to the far point of Base station L, video playback started to stutter. When the test vehicle travelled to the coverage area of Base station S, the test receiver could properly play the video, the program converted to CCTV-1 video automatically. When the test vehicle travelled to the near point of Base station S, the video play smoothly.

The test results showed that the test receiver can automatically complete the base station switching and program switching.

2.3 Conclusion

Through the field trial in Nanjing, the following can be concluded:

1 Coverage range.

Under the same power and modulation and coding schemes (MCS), the coverage range is affected by the operating bandwidth.

Under bandwidth of 5 MHz, the farthest coverage distance is 11.1 km, and the video playback stops at 12.5 km.

Under bandwidth of 10 MHz, the farthest coverage distance is 8.2 km, and the video playback stops at 10.7 km.

2 In the same test area, the faster the vehicle travels, the more obvious the video jamming is.

3 When the terminal mobile moves between different base station, the receiver can automatically switch between different base stations and programs. the receiver can continue to play properly after switching.

CBN will continue to test and build the 5G NR MBS and will keep ITU informed of the latest progress.

3 HPHT and LPLT 5G NR MBS cooperative networking test

3.1 Overview

This test studies the signal coverage and reception of 5G NR MBS under the conditions of key system parameters such as specified transmission power and modulation mode under the cooperative networking of TV tower and mobile cellular network.

3.2 Test environment

The central TV tower provides 5G NR MBS signal coverage for long-distance and wide-area scenarios. The hanging height is 207 meters, the transmitting antenna is 4T4R, the downtilt angle is 4 degrees, the transmitting power is 240 W, the operating frequency is 768-773 MHz, and the modulation method is QPSK.

The two mobile cellular base stations located in Beijing mainly provide deep coverage of 5G NR MBS signals in key areas.

One of the mobile cellular base stations (mobile cell base Station 1) is hung at a height of 50 meters, the transmitting antenna is 4T4R, the downtilt angle is 6 degrees, the transmitting power is 200 W, the frequency is 763-768 MHz, and the modulation mode is 16-QAM.

Another mobile cellular base station (mobile cell base Station 2) is hung at a height of 22 meters, the transmitting antenna is 4T4R, the downtilt angle is 2 degrees, the transmitting power is 120 W, the frequency is 758-763 MHz, and the modulation method is 16-QAM.

Other configuration parameters are shown in Table 5.

TABLE 5

Configuration parameters

Index	Parameter
NR frequency (MHz)	700
NR cell bandwidth (MHz)	5
PRACH format	Format0
PRACH cycle	10
PUCCH format	Format2
SSB sub-carrier spacing (kHz)	15
PBCH cycle (ms)	20
Antenna channels	4
Uplink power control	Enable
AMC	Enable
Terminal	SA: 1T2R (Commercial mobile phone)
RF module specifications	4T4R
Terminal transmit power	The total power of SA shall not exceed 23 dBm
Business type	5G NR TV broadcasting (Video)
Wireless and terminal transmission	IPv6

The mobile cellular base station uses Huawei BBU5900 baseband unit and radio frequency unit RRU5304W.

The terminal uses Huawei's commercial Mate40 Pro.

The program sources adopt two typical resolutions of 576 × 720 (standard definition) and 1080 × 1920 (high definition), and the frame rate is 25 fps. Under the H.265 encoding format, the program bit rates are 250-300 kbit/s and 700-800 kbit/s respectively.

3.3 Key technologies

3.3.1 Program list

User Service Description (USD) file: program list file, which configures the sending information and program names of all programs. Channel 1 is fixedly designed to send USD files. The server sends USD to the terminal APP through channel 1. Each site can deliver the same or different program list. Due to the collaborative network test in this test, the program list issued is the same program list.

The relevant parameters are shown in Table 6.

TABLE 6

Relevant parameters

	Program 1	…	Program 254
Channel number	2		255
Port number	Port Y		Port xx
Frequency point	ARFCN – ValueNR2		ARFCN – ValueNRx
Business channel name	Text 2		Text x
Site type	Site A		Site B

3.3.2 Frequency sweep/frequency hopping

The G-RNTI mapping relation is shown in Table 7.

TABLE 7

G-RNTI mapping relation

	Program 1 (Program list)	Program 1	…	Program 254
G-RNTI	Value X	Value Y		Value XX
Channel number	1	2		255

1 After the modem receives the frequency sweeping command, it will perform sweep frequency on the corresponding frequency band, and try to read the program list at each available frequency point and report it to the APP.

2 Turn on the split frequency reselection function.

3 Support frequency + program setting. The current version already supports program setting, adding the frequency setting function. After the modem receives the command to set the frequency from the APP, it sets the frequency as a high priority. If the set frequency point is not the current working frequency point, the transmitter will try to switch the UE to the target frequency point. Modem will read services after switching.

3.3.3 Signal source switching scheme

The program list (USD file) is sent to UE through channel 1, and the USD file contains program information and frequency point information in all frequency points.

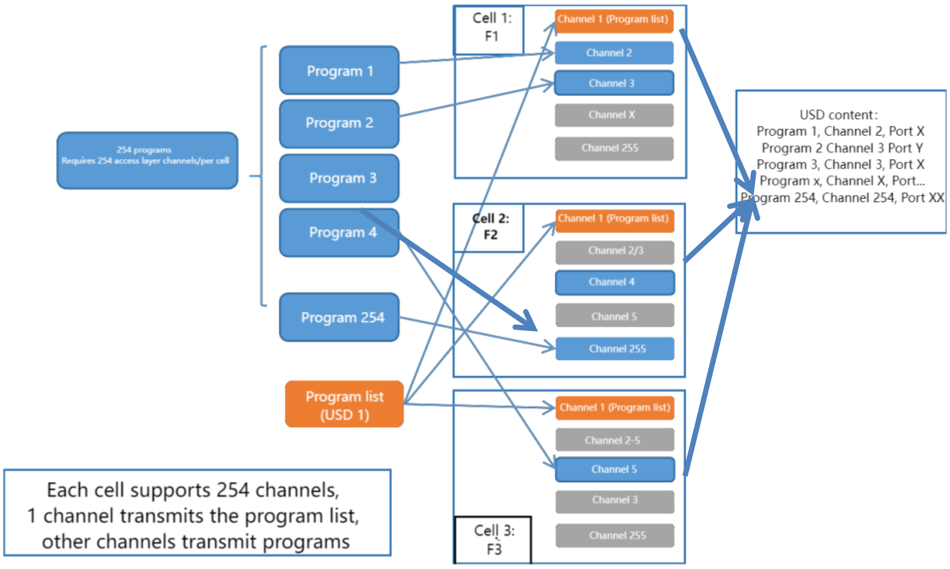
The UE obtains the cell information on the 700 MHz frequency band through frequency scanning, and obtains the program list on each cell frequency point.

The UE obtains the program according to the frequency selected by the user to switch to the corresponding cell, and the frequency corresponding to the program is set as the highest priority. After the user selects a program, the modem is controlled to stay at the corresponding frequency point to receive the program.

Each cell supports 254 channels, 1 channel transmits the program list, and the other channels transmit the program channel/G-RNTI/program for one-to-one mapping. No matter which frequency point the service is provided, the channel used remains the same. The signal source switching scheme is shown in Fig. 12.

FIGURE 12

Signal source switching scheme



3.4 Test results

3.4.1 5G NR MBS basic business

The terminal is tested at a field strength of SS_RSRP = −77 dBm and SINR = 27 dB. The UE receives the broadcast service of the server through the NR multicast broadcast APP. The video playback is clear and smooth.

The basic service status when the terminal only receives the broadcast signal in one cell is shown in Fig. 13.

FIGURE 13

5G NR MBS basic service test results

3.4.2 5G NR MBS cross-cell channel switching

UE receives the broadcast service of TV tower through the 5G NR MBS APP, and switches channel CCTV 1 (mobile cell base station 2) to channel CCTV 1 (mobile cell base Station 1) and to channel CCTV 13 (TV tower) through the APP. Broadcast service reception is normal, and video playback is clear and smooth.

When the terminal is covered by the broadcast signals of two cells at the same time, the service status when the user selects Cell-1 is shown in Fig. 14.

FIGURE 14

5G NR MBS cross-cell channel switching test results

When the terminal is covered by the broadcast signals of three cells at the same time, the service status when the user selects Cell-2 is shown in Fig. 15.

FIGURE 15

5G NR MBS Cross-cell Channel Switching Test Results

3.5 Conclusion

This test verified the signal coverage and reception of 5G NR MBS under the condition of cooperative networking of TV tower and mobile cellular network. New features such as program list, terminal frequency sweep and frequency hopping switching are fully functional and work normally. 5G NR MBS has complete functions in TV tower and mobile cellular network signal coordination, and its performance meets expectations, which further expands the practicability of 5G NR MBS.

4 Laboratory testing of 5G NR MBS in the 700 MHz band

4.1 Overview

In order to test the terminal reception capability, the test of 5G NR MBS was carried out. This test verifies the commercial terminal's support for the operation of 5G NR MBS in the 700 MHz band.

4.2 Test environment

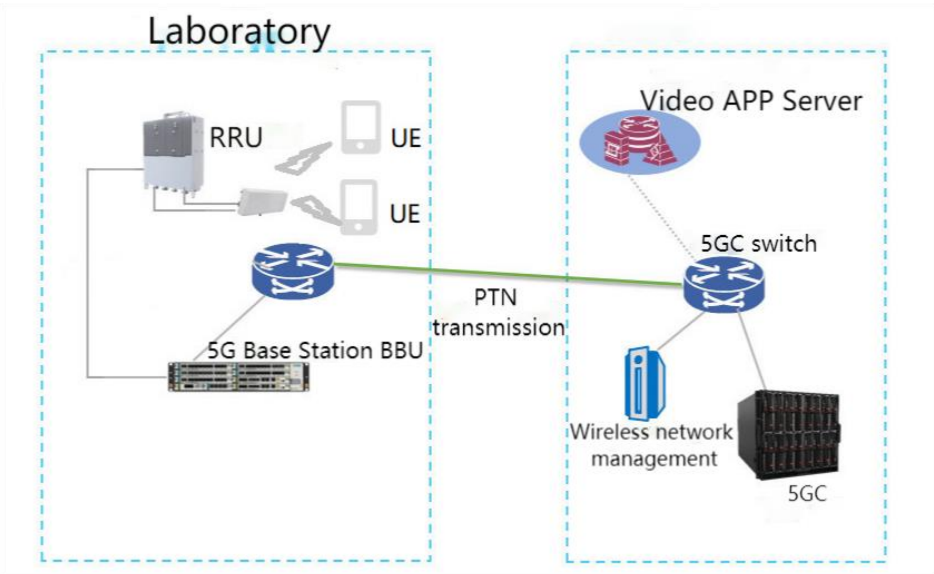
This test is mainly conducted in the laboratory, using the virtual system built in the laboratory. The system architecture is as follows:

4.2.1 System architecture

The architecture of the laboratory test environment is shown in Fig. 16.

FIGURE 16

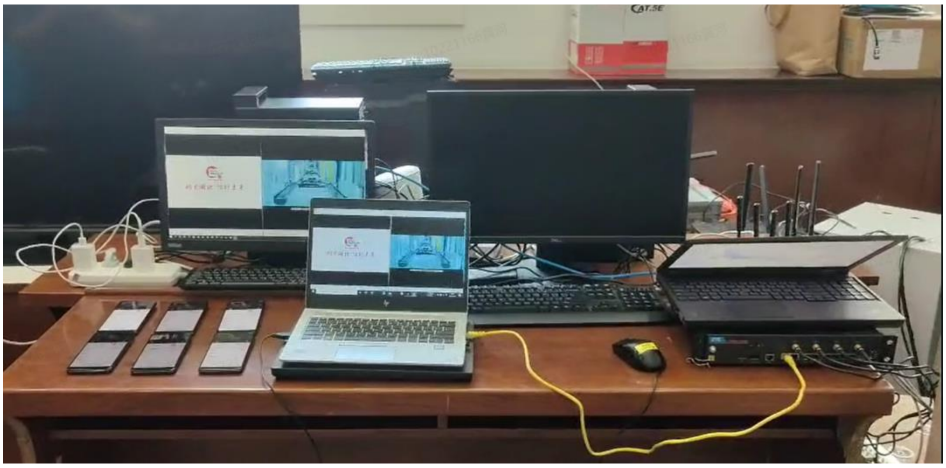
Laboratory test environment architecture



The laboratory equipment is shown in Fig. 17.

FIGURE 17

Laboratory equipment



4.2.2 Base station equipment

ZTE baseband unit BBU (V9200) and RF unit RRU (R9214H) were used for the test.

4.2.2.1 Baseband unit

The ZXRAN V9200 is a baseband unit, which mainly realizes the following functions:

– provide the LTE/NR base station baseband processing functions;

– support 48 dc-power input or by an external ac/dc conversion equipment support 110/220V ac-power input;

– support built-in GNSS receiver, IEEE1588, 1 PPS + TOD and SyncE clock synchronization a variety of ways.

The appearance of ZXRAN V9200 is shown in Fig. 18.

FIGURE 18

BBU for the test

The ZXRAN V9200 contains the following functions, as shown in Table 8.

TABLE 8

Description of boards

Classification	Name	Function
Switching plate	VSWd1	It realizes baseband unit control management, Ethernet switching, transmission interface processing, system clock recovery and distribution, and air interface high level protocol processing

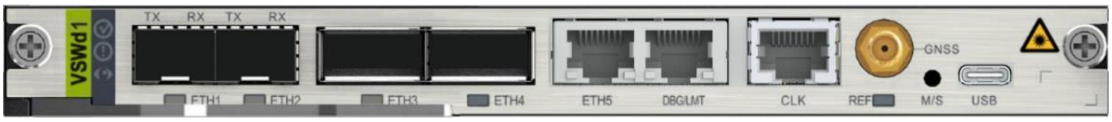
TABLE 8 (*end*)

Classification	Name	Function
Baseband processing board	VBPd0d	Protocols that deal with the physical layer and frame protocols defined by 3GPP
Environmental monitoring board	VEM	Provide site alarm contact and environmental monitoring interface
Power distribution board	VPDc1	Realize protection, filtering, anti-reverse connection of −48V DC input power supply, rated current 50A; support −48V main/standby function, undervoltage alarm, temperature monitoring, voltage and current monitoring
Fan module board	VFC1	System temperature detection control and fan status monitoring, control and reporting

VSWd1 is a switch board that implements baseband unit control and management, Ethernet switching, transmission interface processing, system clock recovery and distribution, and interface high-level protocol processing. The VSWd1 panel is shown in Fig. 19.

FIGURE 19

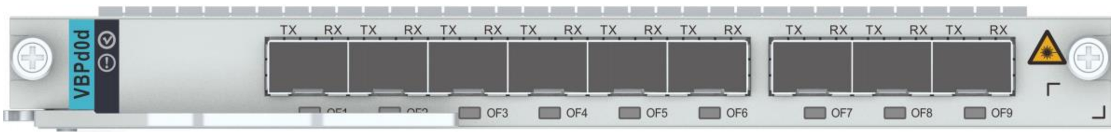
VSWd1 panel



VBPd0d is a baseband processing board used to handle the protocols of the physical layer and the frame protocols defined by 3GPP. The VBPd0d panel is shown in Fig. 20.

FIGURE 20

VSWd1 panel



4.2.2.2 RF unit

ZXRAN R9214H S7200(W) is ZTE's latest 4T4R high power distributed remote radio unit (RRU), based on the latest RAN unified platform design. Figure 21 shows the appearance of R9214H.

FIGURE 21

RRU appearance

The RRU specifications are shown in Table 9.

TABLE 9

RRU specifications

Index	Parameter
Operating frequency band	700 MHz
Capacity configuration	1 × 30 MHz NR Cell 1 × 30 MHz NR Cell + 1 × 10 MHz NR Cell 1 × 30 MHz NR Cell + 1 × 15 MHz NR Cell
Antenna port power	4 × 80 W
Static receiving sensitivity	NR: Single antenna reception −100.2 dBm (20 MHz)

4.2.3 Test Terminal

ZTE S30 5G was used as the test terminal, as shown in Fig. 22.

FIGURE 22

Test terminal

The specifications are shown in Table 10.

TABLE 10

Test terminal specifications

Index	Parameter
Mobile phone model	ZTE S30 5G
Size	Wide: 76.4 mm; Long: 164.8 mm; Thick: 7.9 mm
Weight	210 g
CPU	MTK Dimensity 720
Memory card	Support MicroSD (TF)
Memory	128 GB
Screen size	6.67 inch
Screen resolution	2 400 × 1 080
Screen material	AMOLED
Operating system	Android 11
5G Network	Support 5G (SA/NSA)
4G Network	Support 4G FDD-LTE, 4G TD-LTE
Dual card type	Dual SIM and Dual Standby
SIM card type	Nano SIM
Rear camera main pixel	64 million pixel
Charging interface	Type-C
Data interface	Bluetooth
Headphone jack	3.5 mm

4.3 Lab tests

4.3.1 Test cell configuration

Key configuration parameters of the test cell are shown in Table 11.

TABLE 11

Cell configuration parameters

Index	Parameter
Carrier bandwidth (MHz)	10
subCarrierSpacingCommon	scs15or60
RE reference power (dBm)	17.8

1 The uplink carrier configuration is shown in Fig. 23.

FIGURE 23

Uplink carrier configuration

LDN	Object ID	Carrier bandwidth (MHz)	Band List
NRRadioInfra...	1	10[10]	28

2 The downlink carrier configuration is shown in Fig. 24.

FIGURE 24

Downlink carrier configuration

LDN	Object ID	Carrier bandwidth (MHz)	Band List
NRRadioInfra...	1	10[10]	28

3 SSB frequency configuration is shown in Fig. 25.

FIGURE 25

SSB frequency configuration

subCarrierSpacingCommon	The subcarrier offset of the synchronization signal and the physical broadcast signal block	TypeA DMRS prefix symbol position
scs15or60[scs15or60]	0	pos3[pos3]

4 RE reference power is shown in Fig. 26.

FIGURE 26

RE reference power

LDN	Object ID	User ID	Cell ID	CP service status	Management status	PMI的C...	SSB索引列表	Carrier Description Object Identifier	RE reference power
NRRadioInfra...	1	CPList-1	0	在服[InService]	Unlocked			NRRadioInfrastructure...	178

5 Cell status is shown in Fig. 27.

FIGURE 27

Cell status

NR Carrier Group Identifier	license type	Reserved for operators target	Cell status	Cell service status	Cell energy saving status	Cell commissioning status
1	正式许可[for...	不预留[notReserved]	已激活[ACTI...	在服[InService]		Normal status

4.3.2 Test results

4.3.2.1 5G NR MBS basic services

The terminal is tested at a field strength of SS_RSRP = −65 dBm and SINR = 28 dB. The UE receives the broadcast service of the server through the NR multicast broadcast APP, and the video service is played clearly and smoothly. The test results are shown in Fig. 28.

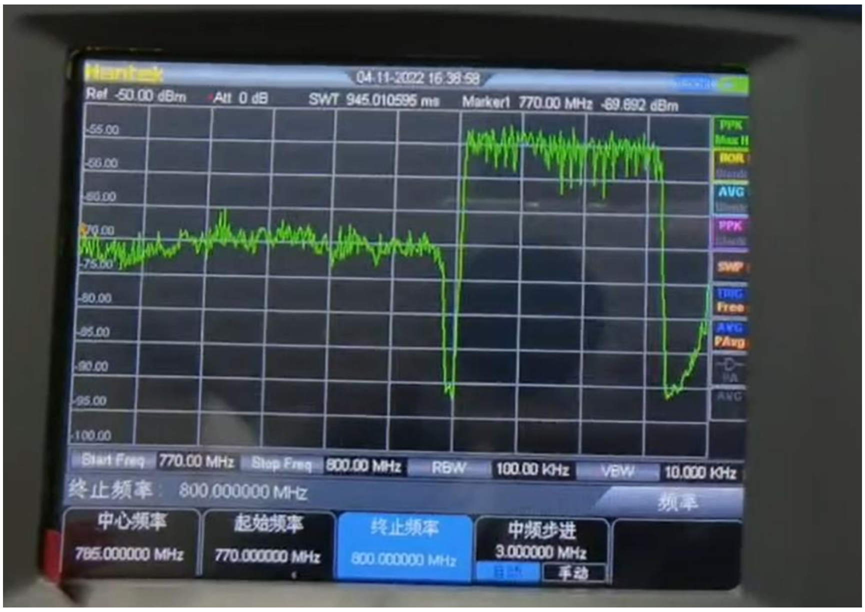
FIGURE 28

Broadcasting service test results

Spectrum scanning, the spectrum range of the strongest signal part is about 10 MHz, which is consistent with the cell configuration, and the spectrum scanning results are shown in Fig. 29.

FIGURE 29

10 MHz cell spectrum scanning result



4.3.2.2 5G NR MBS service channel switching

The UE receives the broadcast service of the server through the 5G NR MBS APP, and switches from channel 1 (CCTV 13) to channel 2 (CCTV 1) through the APP. The broadcast service is received normally, and the video playback is clear and smooth.

1 The test results of Channel 1 are shown in Fig. 30.

FIGURE 30

Channel 1 broadcasting service test results

2 The test results of Channel 2 are shown in Fig. 31.

FIGURE 31

Channel 2 broadcasting service test results

4.3.2.3 Support for different MCS

Broadcast service support is based on the 3GPP 38.214 MCS table. 3GPP defines 38.214 as different MCS used to support different business requirements. To test the terminal's support for different MCS, 7 modes were selected for testing, namely, MCS8, MSC9, MCS11, MCS13, MCS15, MCS17, and MCS18. The MCS index is shown in Table 12.

TABLE 12

MCS index

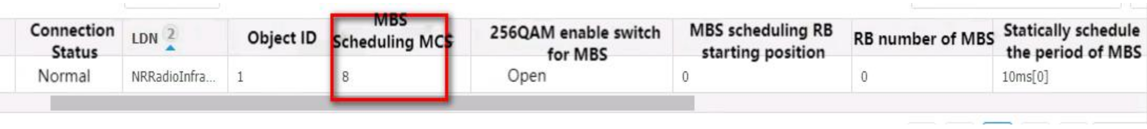
MCS index IMCS	Modulation order Qm	Target code rate R × [1 024]	Spectral efficiency (bit/Hz)
MCS8	2	602	1.1758
MCS9	2	679	1.3262
MCS11	4	378	1.4766
MCS13	4	490	1.9141
MCS15	4	616	2.4063
MCS17	6	438	2.5664
MCS18	6	466	2.7305

The configuration of seven modes is shown in Figs 32 to 38.

1 5G NR MBS scheduling MCS configuration is 8, as shown in Fig. 32.

FIGURE 32

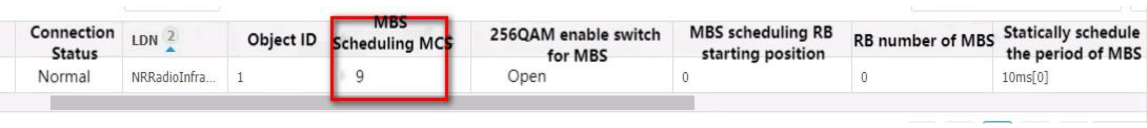
5G NR MBS scheduling MCS configuration 8



2 5G NR MBS scheduling MCS configuration is 9, as shown in Fig. 33.

FIGURE 33

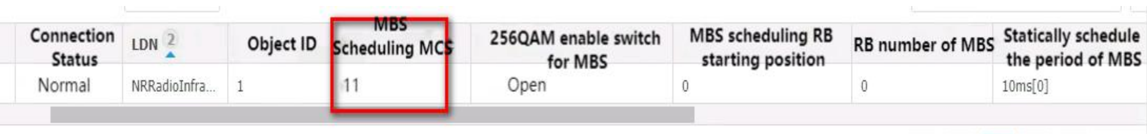
5G NR MBS scheduling MCS configuration 9



3 5G NR MBS scheduling MCS configuration is 11, as shown in Fig. 34.

FIGURE 34

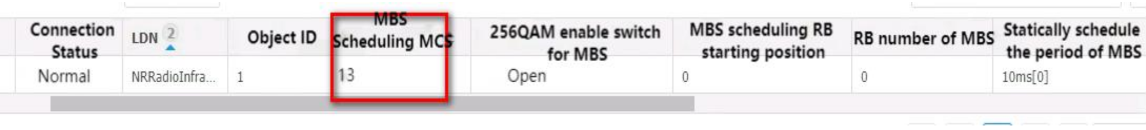
5G NR MBS scheduling MCS configuration 11



4 5G NR MBS scheduling MCS configuration is 13, as shown in Fig. 35.

FIGURE 35

5G NR MBS scheduling MCS configuration 13

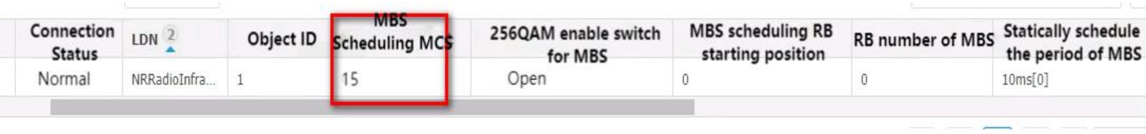


Connection Status	LDN	Object ID	MBS Scheduling MCS	256QAM enable switch for MBS	MBS scheduling RB starting position	RB number of MBS	Statically schedule the period of MBS
Normal	NRRadioInfra...	1	13	Open	0	0	10ms[0]

5 5G NR MBS scheduling MCS configuration is 15, as shown in Fig. 36.

FIGURE 36

5G NR MBS scheduling MCS configuration 15

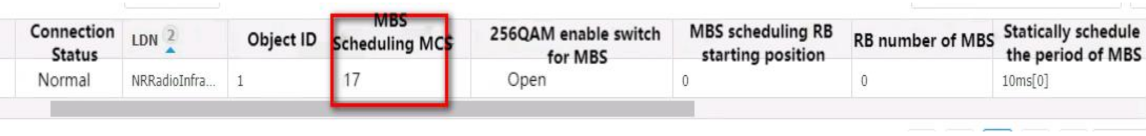


Connection Status	LDN	Object ID	MBS Scheduling MCS	256QAM enable switch for MBS	MBS scheduling RB starting position	RB number of MBS	Statically schedule the period of MBS
Normal	NRRadioInfra...	1	15	Open	0	0	10ms[0]

6 5G NR MBS scheduling MCS configuration is 17, as shown in Fig. 37.

FIGURE 37

5G NR MBS scheduling MCS configuration 17

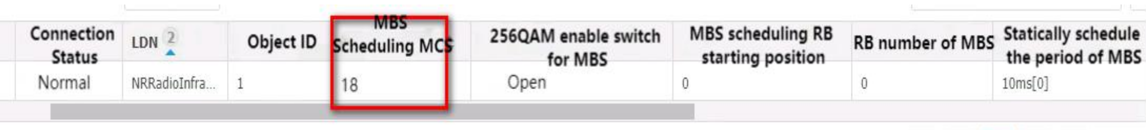


Connection Status	LDN	Object ID	MBS Scheduling MCS	256QAM enable switch for MBS	MBS scheduling RB starting position	RB number of MBS	Statically schedule the period of MBS
Normal	NRRadioInfra...	1	17	Open	0	0	10ms[0]

7 5G NR MBS scheduling MCS configuration is 18, as shown in Fig. 38.

FIGURE 38

5G NR MBS scheduling MCS configuration 18



Connection Status	LDN	Object ID	MBS Scheduling MCS	256QAM enable switch for MBS	MBS scheduling RB starting position	RB number of MBS	Statically schedule the period of MBS
Normal	NRRadioInfra...	1	18	Open	0	0	10ms[0]

According to the test, the UE can receive broadcast services at a fixed MCS level. Table 13 shows the test results.

TABLE 13

Test results of different cell configuration parameters

MCS configuration values	Verification conclusion
8	The UE can normally receive the broadcast service delivered by the broadcast server, and the service is clear and smooth.
9	The UE can normally receive the broadcast service delivered by the broadcast server, and the service is clear and smooth.

TABLE 13 (*end*)

MCS configuration values	Verification conclusion
11	The UE can normally receive the broadcast service delivered by the broadcast server, and the service is clear and smooth.
13	The UE can normally receive the broadcast service delivered by the broadcast server, and the service is clear and smooth.
15	The UE can normally receive the broadcast service delivered by the broadcast server, and the service is clear and smooth.
17	The UE can normally receive the broadcast service delivered by the broadcast server, and the service is clear and smooth.
18	The UE can normally receive the broadcast service delivered by the broadcast server, and the service is clear and smooth.

4.4 Conclusion

According to laboratory tests, the reception of 5G NR system can be realized in 700 MHz band. Next, CBN will prepare to conduct field trail tests to further verify the reception capacity of 5G NR MBS system.

Attachment

5G NR MBS basic service test video

Video-NR MBS Basic Services.mp4

5 The Test Report of the Wireless Digital Multimedia Broadcasting Network

5.1 Objective

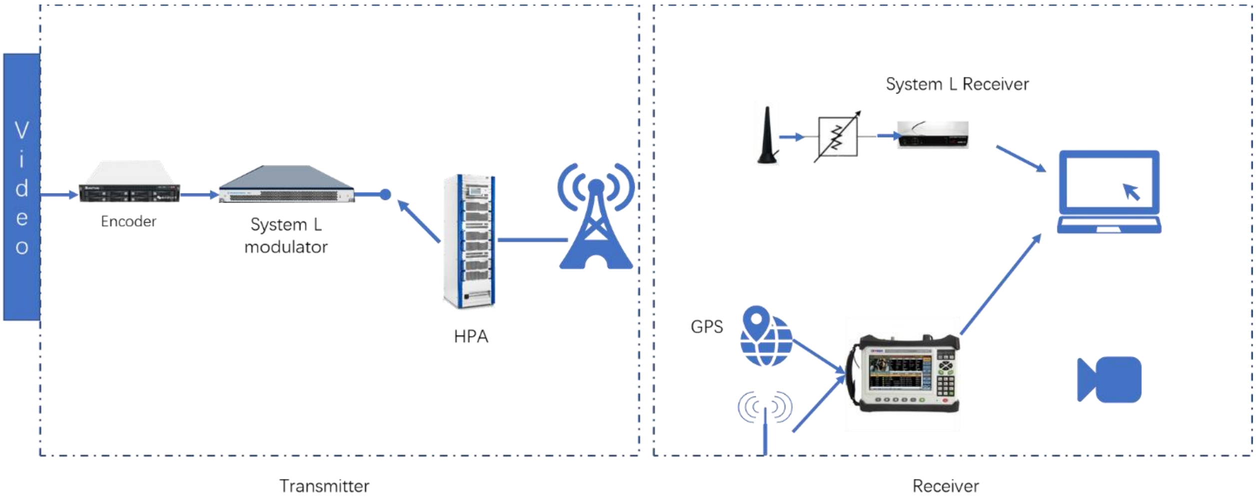
In order to evaluate the coverage performance of LTE-based 5G broadcasting system (Multimedia System L) in high-power and high-tower downlink broadcasting scenarios, Pengcheng Laboratory together with Tsinghua University, Shanghai Jiao Tong University (SJTU) and other teams carried out the field trials of System L in Shenzhen from 18 August 2022. The tests mainly focus on the coverage performance and reception capacity of in-vehicle mobile reception for high-definition TV programmes.

5.2 The test system

The test system is composed of transmitting and receiving systems, the transmitting system is located in Shenzhen TV Tower on Wutong Mountain, and the receiving system is located in the test vehicle. The functional block diagram of the test system is shown in Fig. 39.

FIGURE 39

The block diagram of the test system



5.2.1 Transmitting system

During the test, the transmission frequency of 682 MHz is used for System L with the RF bandwidths of 5 MHz. The test program streams are provided by Shenzhen TV Urban Channel. Table 14 lists the parameters of the test streams for System L.

TABLE 14

The parameters and the interfaces of the test streams

Video coding	H.264
Code rate	9 Mbit/s
Interface	IP

A self-developed System L exciter is provided by SJTU as shown in Fig. 40.

FIGURE 40

System L exciter

The power amplifier is PMU901 produced by Rohde & Schwarz company (as shown in Fig. 41) with the maximum output power of 3 000 W. The antennas are mounted on the top of the transmission tower.

FIGURE 41

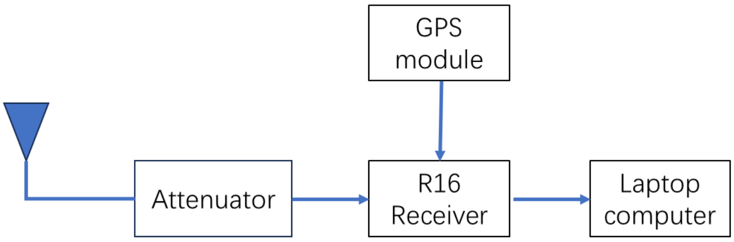
The power amplifier

5.2.2 Receiving system

The block diagram of the System L receiving system developed by SJTU is shown in Fig. 42. The gain of receiving antenna is −2 dB, the noise figure of receiver is 5 dB.

FIGURE 42

The block diagram of SYSTEM L (called R16 in the figure) receiving system

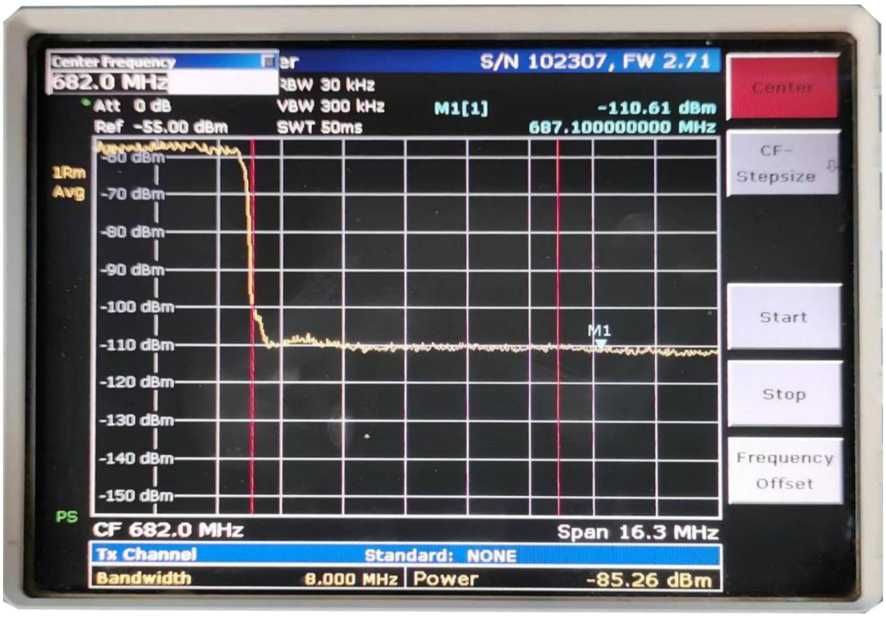


5.3 Test preparation

Considering that the noise floor has certain influence on the test results during the field trial, the noise floor test was carried out in the corresponding frequency band before the field trial. During the noise floor test, the antenna is placed on the roof of the car, and the spectrum is observed in real time by the spectrum analyser, and the test results are shown in Fig. 43. The noise floor is relatively clean in the 682 MHz band, and there are DTMB transmitting signals in the 666-674 MHz bands at the adjacent frequency, which are the signals transmitted from the Wutong mountain transmission tower, and the transmitting power is 2.5 kW.

FIGURE 43

Noise floor (678-686 MHz)

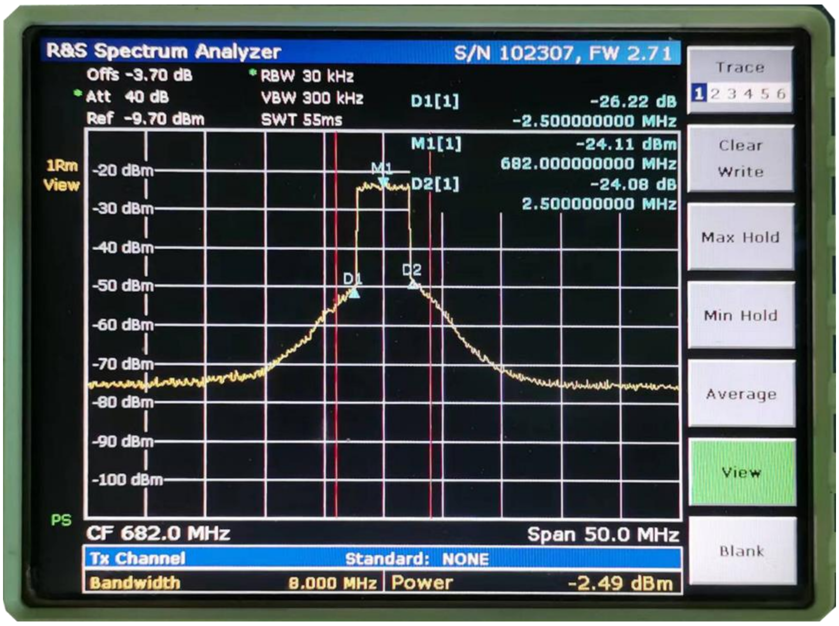


5.4 Test results

During the test, the operating modes of MCS20, MCS14 and MCS9 were selected, and the specific parameters are shown in Tables 2 to 4. The transmit power is set to 260 W and the spectrum out of the power amplifier from coupling port is shown in Fig. 44.

FIGURE 44

The spectrum of the power amplifier for System L



During the tests, the SNR output from the equalizer of System L receiver, the block error rate (BLER) as well as the subjective assessment of the video quality are collected and recorded for the result analysis.

5.4.1 MCS20 mode

Different parameter sets can be supported by System L according to different requirements of the transmission data rate and spectral efficiency. To compare with the digital terrestrial television broadcasting system, the operating mode of MCS20 with 64-QAM constellation is first selected. The spectral efficiency under 5 MHz bandwidth is 2.14 bits/s/Hz as shown in Table 15.

TABLE 15

The parameters of MCS20

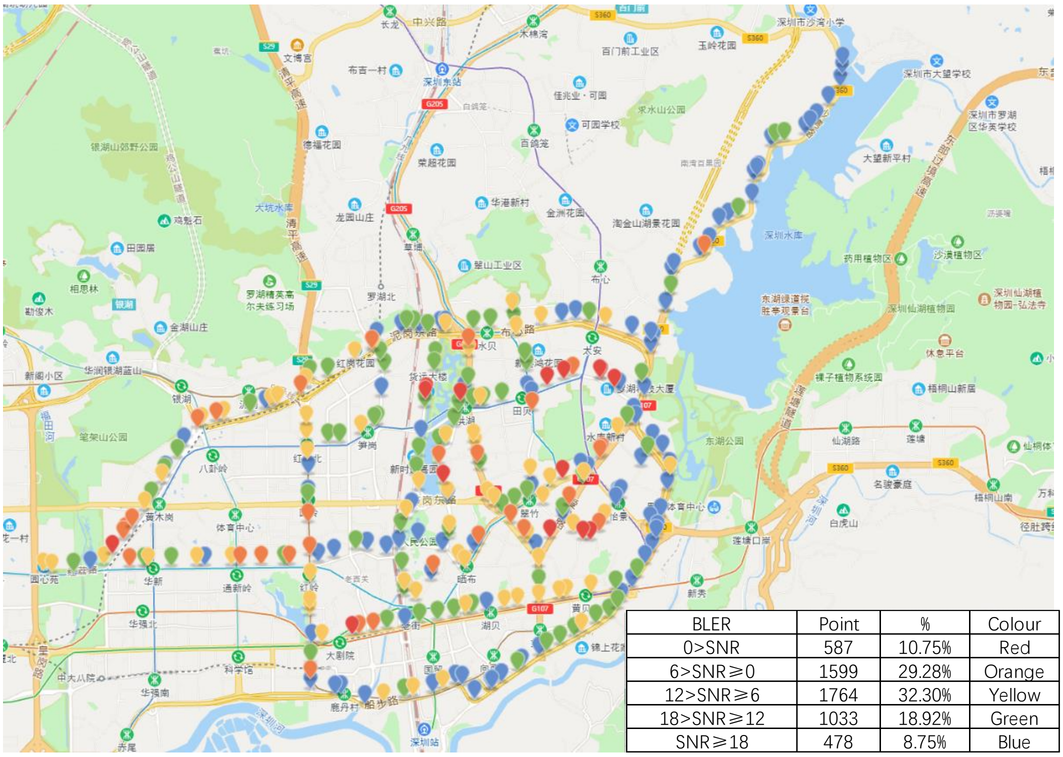
Item	Value
Bandwidth	4.5 MHz
Modulation and coding scheme	MCS20
Cyclic-prefix	200 μs
FFT length	6K
Subcarrier spacing	1.25 kHz/2.5 kHz
Constellation	64-QAM
FEC code rate	0.551
Payload data rate	9.66 Mbit/s
Spectral efficiency	2.14 bits/s/Hz

1) The performance of the subcarrier spacing of 1.25 kHz

With this parameter combination, the SNR values are below 12 dB over 80% of the test section (the SNR threshold of error free for MCS20 is about 14 dB under AWGN), as shown in Fig. 45. Here, EQ_SNR means the SNR after equalization.

FIGURE 45

EQ_SNR results for MCS20 with subcarrier spacing of 1.25 kHz

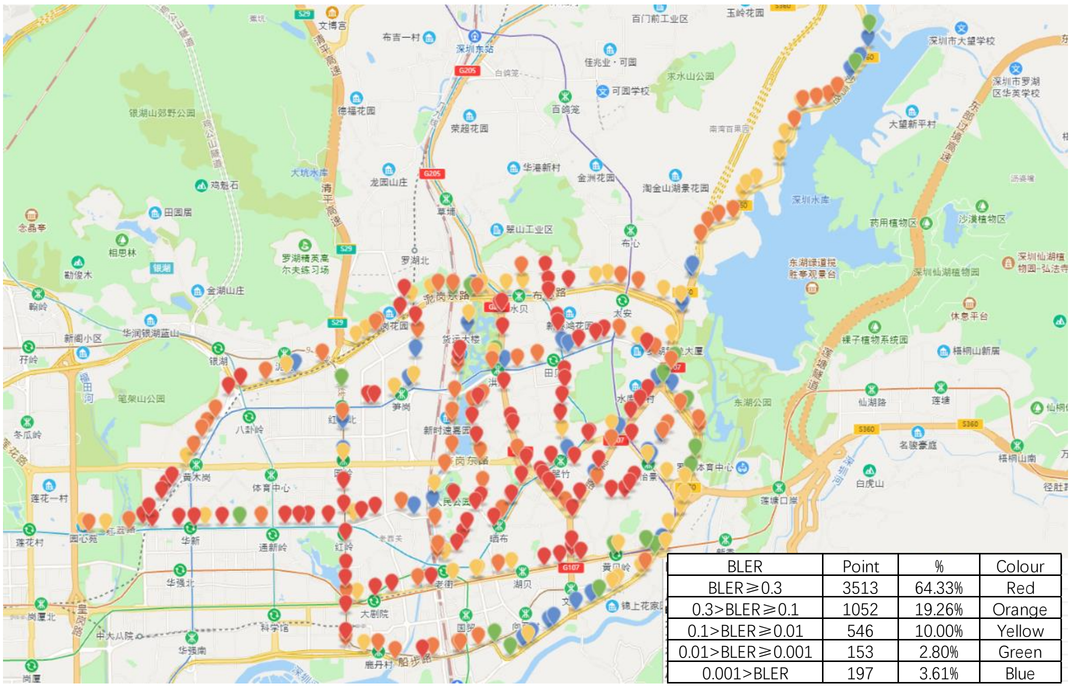


BLER	Point	%	Colour
0>SNR	587	10.75%	Red
6>SNR≥0	1599	29.28%	Orange
12>SNR≥6	1764	32.30%	Yellow
18>SNR≥12	1033	18.92%	Green
SNR≥18	478	8.75%	Blue

As shown in Fig. 46, in more than 95% of mobile reception scenarios, the performance of BLER is greater than 1% for MCS20 mode. In a small number (5%) of mobile reception scenarios and some fixed reception scenarios, BLER is less than 1% or no bit errors, which can achieve slight lag or smooth video playback. It coincides with the EQ_SNR results.

FIGURE 46

BLER results for MCS20 with subcarrier spacing of 1.25 kHz



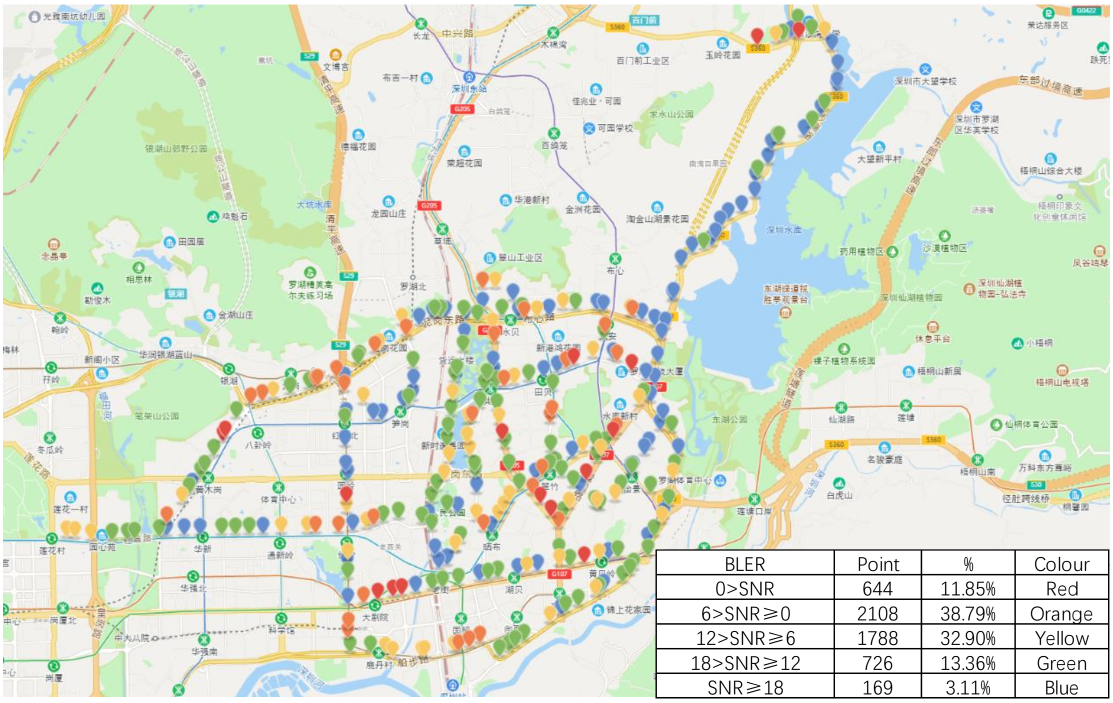
BLER	Point	%	Colour
BLER≥0.3	3513	64.33%	Red
0.3>BLER≥0.1	1052	19.26%	Orange
0.1>BLER≥0.01	546	10.00%	Yellow
0.01>BLER≥0.001	153	2.80%	Green
0.001>BLER	197	3.61%	Blue

2) The performance of the subcarrier spacing of 2.5 kHz

According to the field trial results, the difference in EQ_SNR between the subcarrier spacing of 1.25 kHz and 2.5 kHz is very small, and the difference cannot be distinguished from the statistical results which are shown in Figs 47 and 48.

FIGURE 47

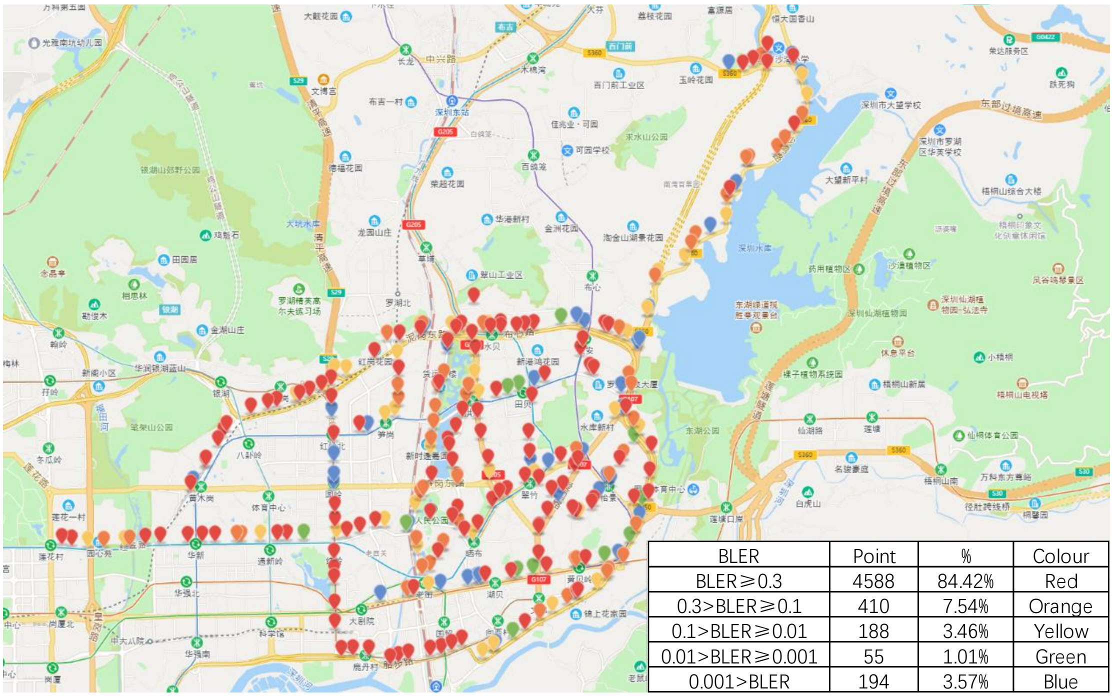
EQ_SNR results for MCS20 with subcarrier spacing of 2.5 kHz



BLER	Point	%	Colour
0>SNR	644	11.85%	Red
6>SNR⩾0	2108	38.79%	Orange
12>SNR⩾6	1788	32.90%	Yellow
18>SNR⩾12	726	13.36%	Green
SNR⩾18	169	3.11%	Blue

FIGURE 48

BLER results for MCS20 with subcarrier spacing of 2.5 kHz



BLER	Point	%	Colour
BLER⩾0.3	4588	84.42%	Red
0.3>BLER⩾0.1	410	7.54%	Orange
0.1>BLER⩾0.01	188	3.46%	Yellow
0.01>BLER⩾0.001	55	1.01%	Green
0.001>BLER	194	3.57%	Blue

According to the measurement results, the system performance even partially regresses when the subcarrier spacing is adjusted from 1.25 kHz to 2.5 kHz. The proportion of BLER greater than 30% increased from 64% to 84%, while the proportion of BLER less than 0.1% decreased from 3.61% to 3.57%.

5.4.2 MCS14 mode

The parameters of MCS14 mode are shown in Table 16.

TABLE 16

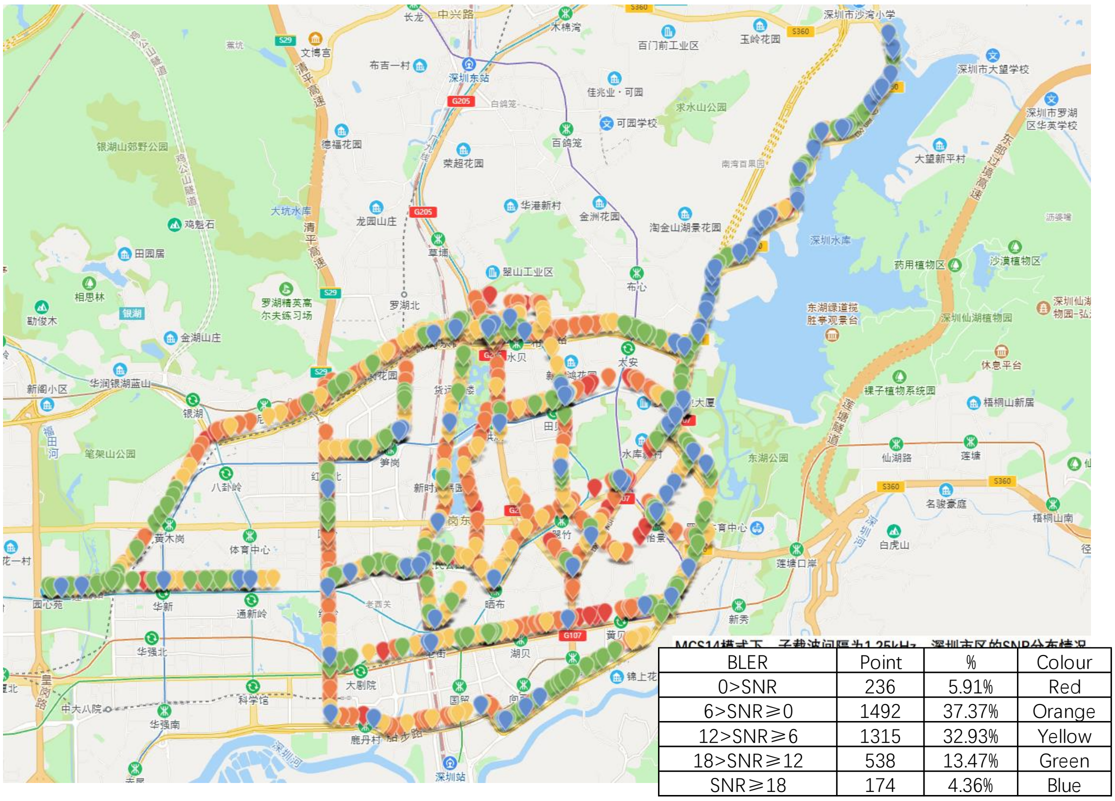
The parameters of MCS14

Item	Value
Bandwidth (MHz)	4.5
Modulation and coding scheme	MCS14
Cyclic-prefix (μs)	100
FFT length	3 072
Subcarrier spacing (kHz)	1.25
Constellation	16-QAM
FEC code rate	0.60
Payload data rate (Mbit/s)	6.295
Spectral efficiency (bits/s/Hz)	1.40

In many tests in Shenzhen, the EQ_SNR values measured by the System L receiver remained stable. Throughout the entire urban test section, SNR values below 12 dB are about 80% of the test sections (the SNR threshold of error free for MCS14 is about 10.5 dB under white Gaussian noise), as shown in Figs 49 and 50.

FIGURE 49

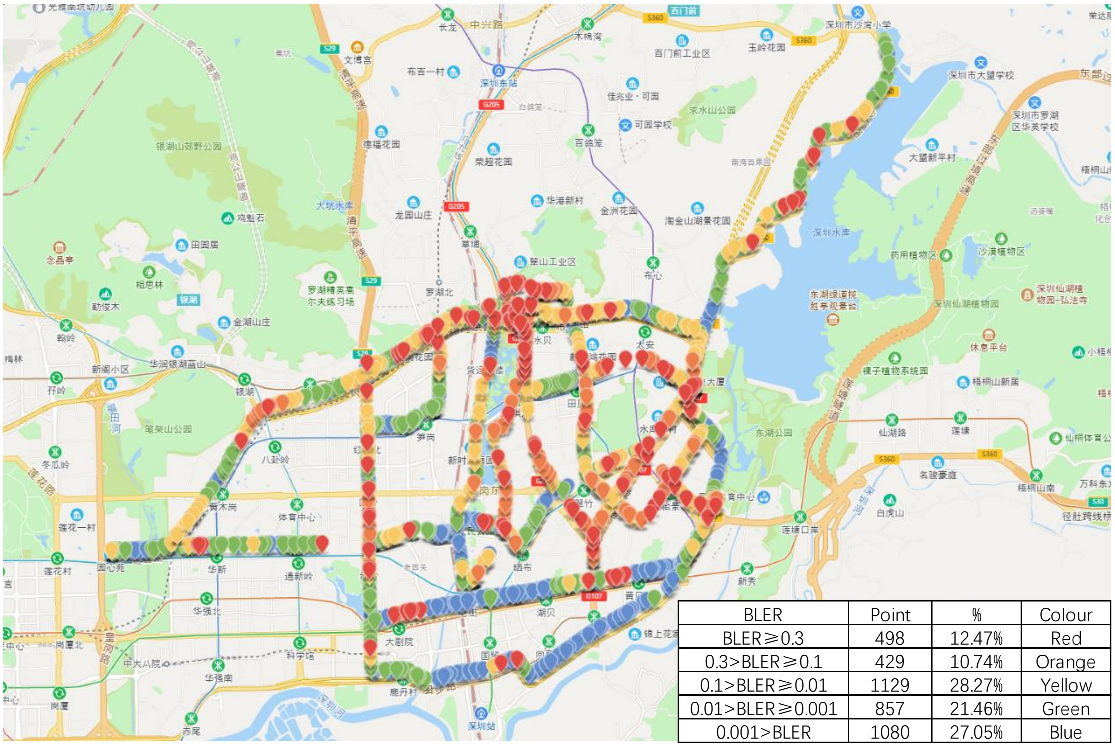
EQ_SNR results for MCS14 with subcarrier spacing of 1.25 kHz



BLER	Point	%	Colour
0>SNR	236	5.91%	Red
6>SNR⩾0	1492	37.37%	Orange
12>SNR⩾6	1315	32.93%	Yellow
18>SNR⩾12	538	13.47%	Green
SNR⩾18	174	4.36%	Blue

FIGURE 50

BLER results for MCS14 with subcarrier spacing of 1.25 kHz



BLER	Point	%	Colour
BLER⩾0.3	498	12.47%	Red
0.3>BLER⩾0.1	429	10.74%	Orange
0.1>BLER⩾0.01	1129	28.27%	Yellow
0.01>BLER⩾0.001	857	21.46%	Green
0.001>BLER	1080	27.05%	Blue

According to the field trial results, the BLER lower than 1% is 48% of test sections which is indicated as blue or green dot on the map, and the video may be played slightly stuttered or smoothly at these dots.

5.4.3 MCS9 mode

The parameters of MCS9 are shown in Table 17.

TABLE 17

The parameters of MCS9

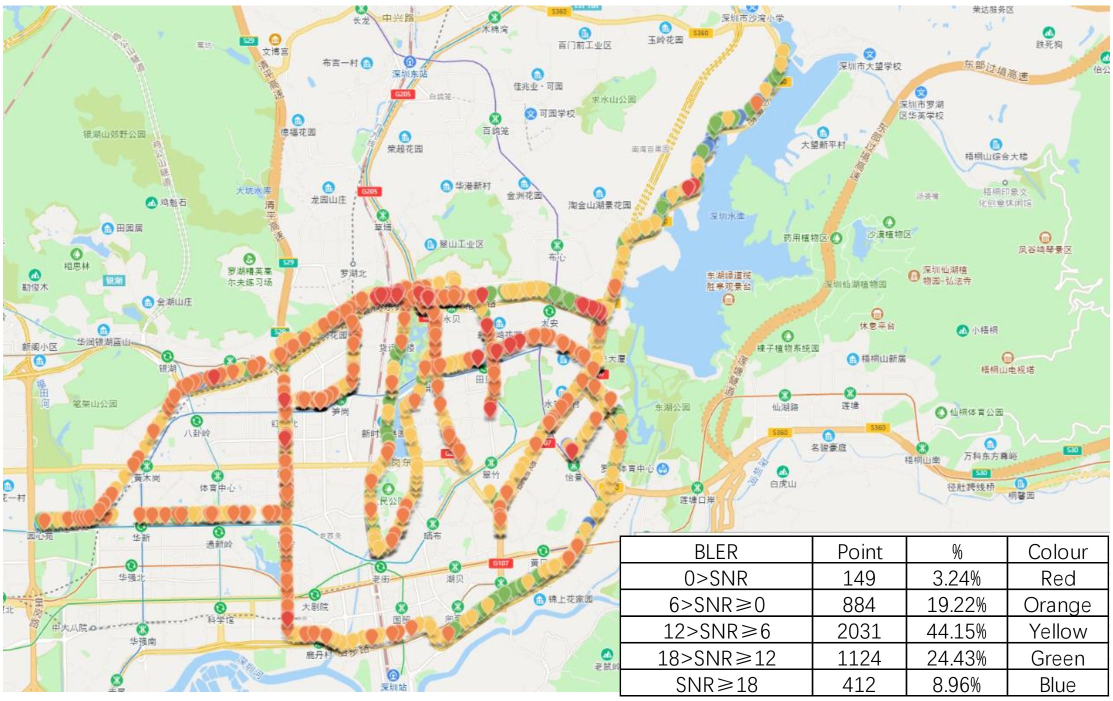
Item	Value
Bandwidth (MHz)	4.5
Modulation and coding scheme	MCS9
Cyclic-prefix (μs)	100
FFT length	3072
Subcarrier spacing (kHz)	1.25 / 2.5
Constellation	QPSK
FEC code rate	0.74
Payload data rate (Mbit/s)	3.908
Spectral efficiency (bit/s/Hz)	0.868

1) The performance of the subcarrier spacing of 1.25 kHz

When using MCS9 mode, the values of EQ_SNR measured by the System L receiver are essentially the same as those measured in MCS14 and MCS20 modes. Throughout the entire test sections, SNR below 6 dB is about 22% of the test sections (the SNR threshold of error free for MCS9 is about 4.4 dB under white Gaussian noise). The test results are shown in Figs 51 and 52.

FIGURE 51

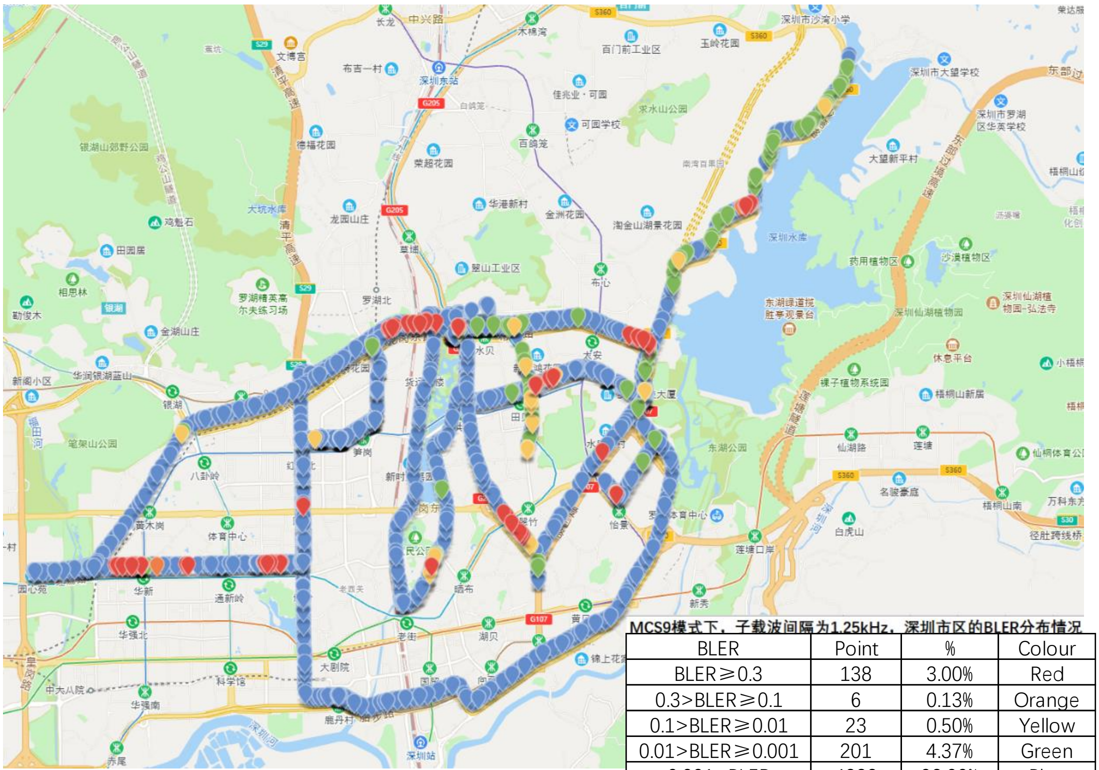
EQ_SNR results for MCS9 with subcarrier spacing of 1.25 kHz



BLER	Point	%	Colour
0>SNR	149	3.24%	Red
6>SNR⩾0	884	19.22%	Orange
12>SNR⩾6	2031	44.15%	Yellow
18>SNR⩾12	1124	24.43%	Green
SNR⩾18	412	8.96%	Blue

FIGURE 52

BLER results for MCS9 with subcarrier spacing of 1.25 kHz



MCS9模式下，子载波间隔为1.25kHz，深圳市区的BLER分布情况

BLER	Point	%	Colour
BLER≥0.3	138	3.00%	Red
0.3>BLER≥0.1	6	0.13%	Orange
0.1>BLER≥0.01	23	0.50%	Yellow
0.01>BLER≥0.001	201	4.37%	Green
0.001>BLER	4232	92.00%	Blue

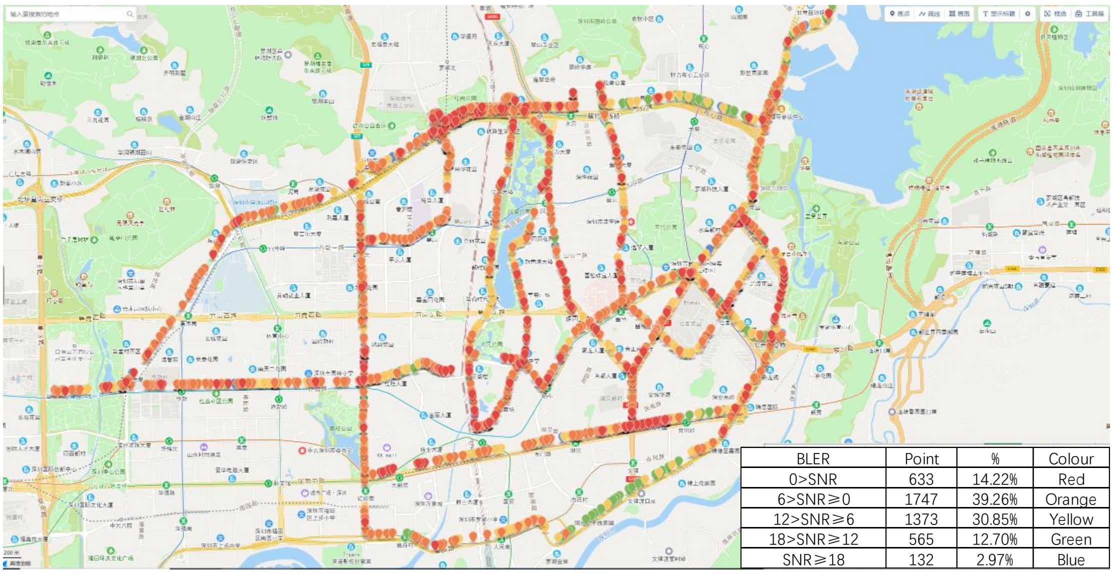
The BLER will be greater than 1% on only 3% of the test sections when using the MCS9 mode with the subcarrier spacing of 1.25 kHz. The video can be played smoothly in the remaining 96% test sections.

2) The performance of the subcarrier spacing of 2.5 kHz

As shown in Figs 53 and 54, the overall performance of the System L receiver shows a significant decline compared with the performance of subcarrier spacing of 1.25 kHz when using MCS9 mode with subcarrier spacing of 2.5 kHz.

FIGURE 53

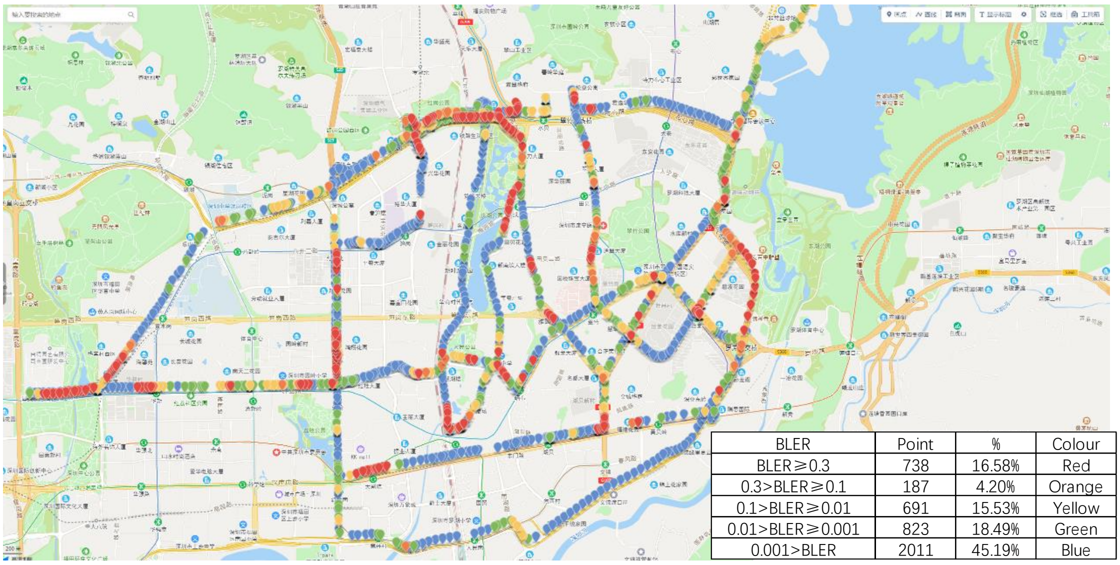
EQ_SNR results for MCS9 with subcarrier spacing of 2.5 kHz



BLER	Point	%	Colour
0>SNR	633	14.22%	Red
6>SNR≥0	1747	39.26%	Orange
12>SNR≥6	1373	30.85%	Yellow
18>SNR≥12	565	12.70%	Green
SNR≥18	132	2.97%	Blue

FIGURE 54

BLER results for MCS9 with subcarrier spacing of 2.5 kHz



BLER	Point	%	Colour
BLER⩾0.3	738	16.58%	Red
0.3>BLER⩾0.1	187	4.20%	Orange
0.1>BLER⩾0.01	691	15.53%	Yellow
0.01>BLER⩾0.001	823	18.49%	Green
0.001>BLER	2011	45.19%	Blue

According to statistics, the BLER greater than 1% is about 35% of the test sections, and the video will have obvious stuttering, which is much higher than the proportion (3%) at 1.25 kHz subcarrier spacing, and the proportion of completely error-free sections drops from 92% to 45%.

6 5G NR MBS network planning and trial

6.1 Overview

This contribution studies the 5G NR MBS network planning scheme with core network, cellular base station and TV Tower networking technology. By deploying TV Tower and mobile cellular base stations in the Beijing area, and using technologies such as programme sources and Service ID, the 5G NR MBS core network can be dual-connected/multiple-connected in one station to achieve flexible networking.

6.2 Network architecture

6.2.1 Programme source settings

To carry out 5G NR MBS, the base station needs to be connected to the broadcast core network functions. The broadcast core network function and the telecom core network function (referring to the 5G broadcast communication network function set defined by 3GPP, such as AMF, SMF and UPF. Hereinafter collectively referred to as the telecom core network function) can be deployed in the same physical location or separately. The base station can connect to the core network functions of multiple different operators and can be configured with different PLMN numbers. Use ServiceID to distinguish different operating organizations. ServiceID exists in MTCH. The base station reads the cell SIB (Signal In Band) to obtain the MCCH configuration; reads the MCCH to obtain the MTCH configuration corresponding to the selected service TMGI (obtains the ServiceID); and receives broadcast data according to the MTCH configuration. ServiceID is set from 0 to 9 according to the number of operators, corresponding to 10 different operating agencies, and can be increased according to demand; or it can be set from one to four levels according to the national administrative divisions.

For example, the broadcast core network can be set to four levels: national, provincial, municipal, and county. Each level is assigned a different Service ID, which is ServiceID 0, ServiceID 1, ServiceID 2, and ServiceID 3 in order. Provinces, cities and counties can transmit programs through self-built broadcast core network functions, or upload or download programmes to the core network functions of the upper or lower administrative divisions, or upload them to the national core network functions for program broadcast. ServiceID is determined by the level of the core network functions, not by the level of the program channel. For example, the ServiceID of national, provincial, and municipal programmes broadcast through county-level core network functions is ServiceID 3. PLMN supports flexible configuration in this networking method. Service ID assignment example is shown in Table 18.

TABLE 18

Service ID assignment

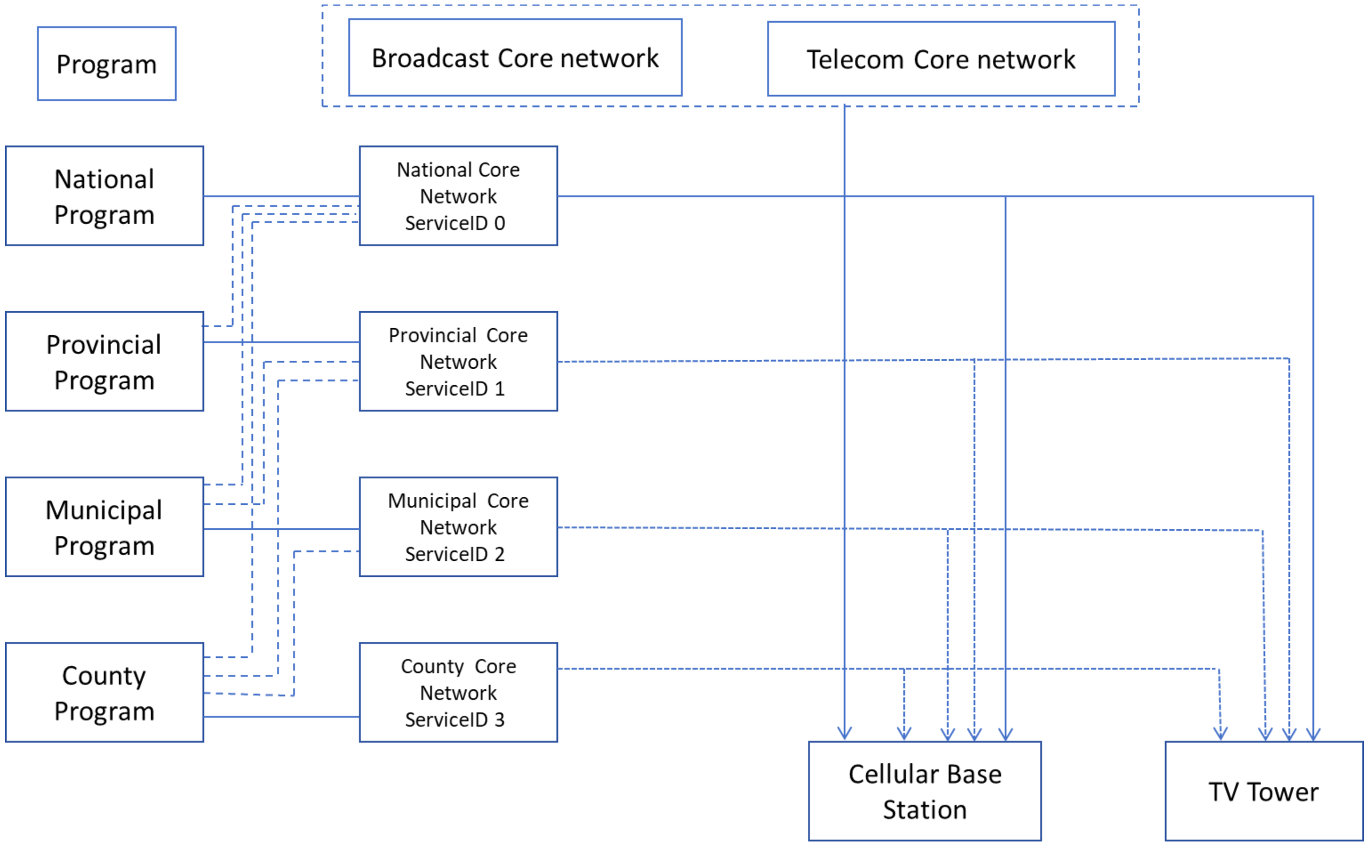
Core network function / **Programme**	**National**	**Provincial**	**Municipal**	**Country**
National programme	0	1	2	3
Provincial programme	0	1	2	3
Municipal programme	0	1	2	3
Country programme	0	1	2	3

6.2.2 Network architecture of broadcast core network and telecom core network

The network architecture of broadcast core network and telecom core network is shown in Fig. 55.

FIGURE 55

Network architecture



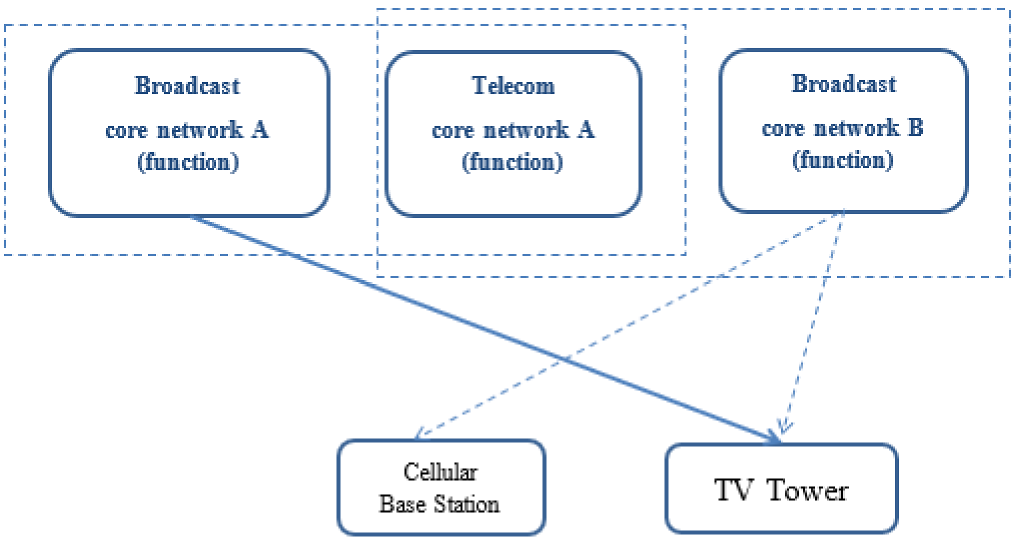
6.3 Beijing trial case

6.3.1 Network architecture

The network architecture of this trial is shown in Fig. 56.

FIGURE 56

Network Architecture of Beijing Trial



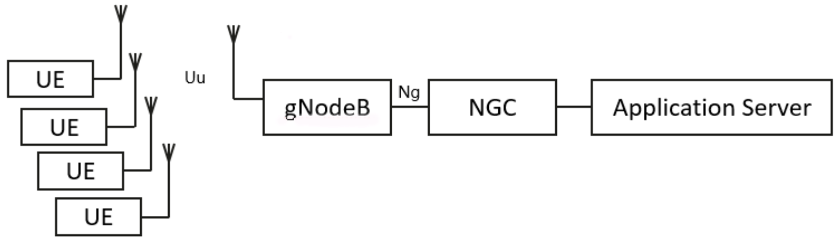
6.3.2 Beijing trial

6.3.2.1 Broadcasting basic services

The broadcasting basic service trial plan is shown in Table 19.

TABLE 19

Broadcasting Basic Service Trial Plan

Testing purposes:	1 Verify support for NR MBS functionality. 2 Verification of 5G NR MBS functionality supporting 15 kHz subcarrier spacing. 3 gNB supports MCCH/MTCH transmission through PDCCH and PDSCH. 4 gNB supports broadcast services in the form of PTM. 5 UE supports receiving broadcast services in IDLE state.
Networking plan:	
Preconditions:	1 Test using mobile phone terminals with 5G commercial SoC/baseband chips. 2 gNB, terminal hardware and software are working normally. 3 The test terminal is pre-installed with the NR MBS APP that supports broadcast services. 4 gNB works as follows: CFR configuration 5 MHz, 10 MHz, subcarrier spacing 15 kHz. 5 The Application Server is configured to support streaming video broadcasting business capabilities. Support channel one, the video format is: H.265 encoding, bit rate 300 kbit/s, VBR, resolution 720 ×576; support channel two, the video format is: H.265 encoding, bit rate 500 kbit/s, VBR, resolution 1 920 × 1 080. 6 The broadcast session is successfully established and Application Server starts broadcast streaming push.
Test steps:	1 5 terminals stay in the cell when they are powered on and remain in the IDLE state. Check the system messages SIB1 and SIB20 received by the terminal side; check whether the terminal successfully receives the MCCH, that is, the MBSBroadcastConfiguration-r17 message. 2 The UE receives the broadcast service from the server through the APP. The APP switches to channel one to check whether the broadcast service is normal and the video definition is normal; the APP switches to channel two and checks whether the broadcast service is normal and the video definition is normal.
Test results:	1 In Step 1, the UE side can successfully receive SIB1, SIB20, MBSBroadcastConfiguration-r17. SIB1 contains searchSpaceMCCH-r17 and searchSpaceMTCH-r17, SIB20 contains CFR bandwidth information, and the MBSBroadcastConfiguration-r17 message contains MBS session information, TMGI identification, and other MBS-related cell configurations. 2 In Step 2, the UE can successfully receive the specified channel data according to the MBSBroadcastConfiguration-r17 content, with smooth video quality and clear sound.

The programme information scanned by the APP and the program playback quality are shown in Fig. 57.

FIGURE 57

Programme information and playback quality scanned by the APP

6.3.2.2 Broadcasting service modulation method

The broadcasting service modulation method is shown in Table 20.

TABLE 20

Broadcasting service modulation method

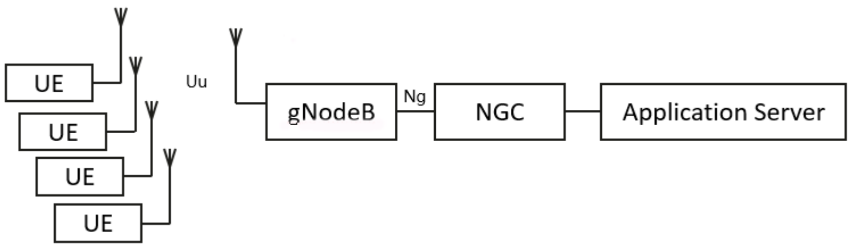
Testing purposes:	gNB broadcasting service supports QPSK, 16-QAM, and 64-QAM modulation methods.
Networking method:	
Preconditions:	1 Test using mobile phone terminals with 5G commercial SoC/baseband chips. 2 gNB, terminal hardware and software are working normally. 3 The test terminal is pre-installed with the NR MBS APP that supports broadcast services. 4 gNB works as: CFR configuration 5 MHz, 10 MHz, MCS code table is 38214 Table 5.1.3.1-1: MCS index Table 33 for PDSCH, MCS=9∈[0,9] (QPSK). 5 Application Server is set to support streaming video broadcast service. Support channel one, the video format is: H.265 encoding, bit rate 300 kbit/s, VBR, resolution 720 × 576; support channel two, the video format is: H.265 encoding, bit rate 500 kbit/s, VBR, resolution 1 920 × 1 080. 6 The broadcast session is successfully established and Application Server starts broadcast streaming push.

TABLE 20 (*end*)

Test steps:	1 5 terminals are powered on and reside in the cell. Check the system messages SIB1 and SIB20 received by the terminal; check whether the terminal successfully receives the MCCH, that is, the MBSBroadcastConfiguration-r17 message. 2 The UE receives the broadcast service from the server through the APP. The APP switches to channel one to check whether the broadcast service is normal and the video definition is normal; the APP switches to channel two and checks whether the broadcast service is normal and the video definition is normal. 3 Change gNB MCS=11∈[10,16] (16-QAM) and MCS=17∈[17,28] (64-QAM) for testing respectively.
Test results:	1 In Step 1, the UE can successfully receive SIB20 and successfully receive MBSBroadcastConfiguration-r17 according to the content of SIB20. 2 In Step 2, the UE can successfully receive the specified channel data according to the content of MBSBroadcastConfiguration-r17; the video quality is smooth and the sound is clear. 3 In Step 3, the gNB can send MCCH and MTCH in the specified modulation method, and the UE can receive MCCH and MTCH in the specified modulation method. The video is smooth and the sound is clear.

6.3.2.3 5G NR MBS emergency broadcast

The 5G NR MBS emergency broadcast test plan is shown in Table 21.

TABLE 21

5G NR MBS Emergency Broadcast Test Plan

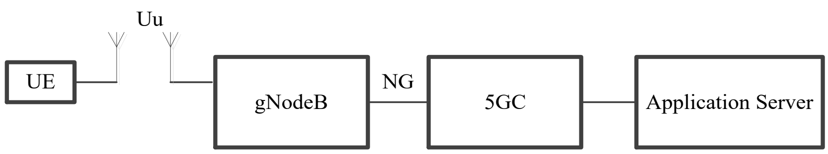
Testing purposes:	5G NR MBS supports emergency broadcast function.
Networking method:	
Preconditions:	1 gNB, terminal hardware and software are working normally. 2 Use 5G commercial SoC/baseband chip mobile phone terminals for testing. Prepare two test terminals with 700 MHz NR bandwidth capability. The 2 terminals are configured without SIM cards. 3 The Application Server is configured to support streaming video broadcast services. Support channel one, the video format is: H.265 encoding, bit rate 300 kbit/s, VBR, resolution 720 × 576; support channel two, the video format is: H.265 encoding, bit rate 1 Mbit/s, VBR, resolution 1 920 × 1 080. 4 The core network supports the emergency broadcast push function, and the APP supports the emergency broadcast pop-up function. 5 The test terminal is pre-installed with the CBN NR MBS APP that supports broadcast services.

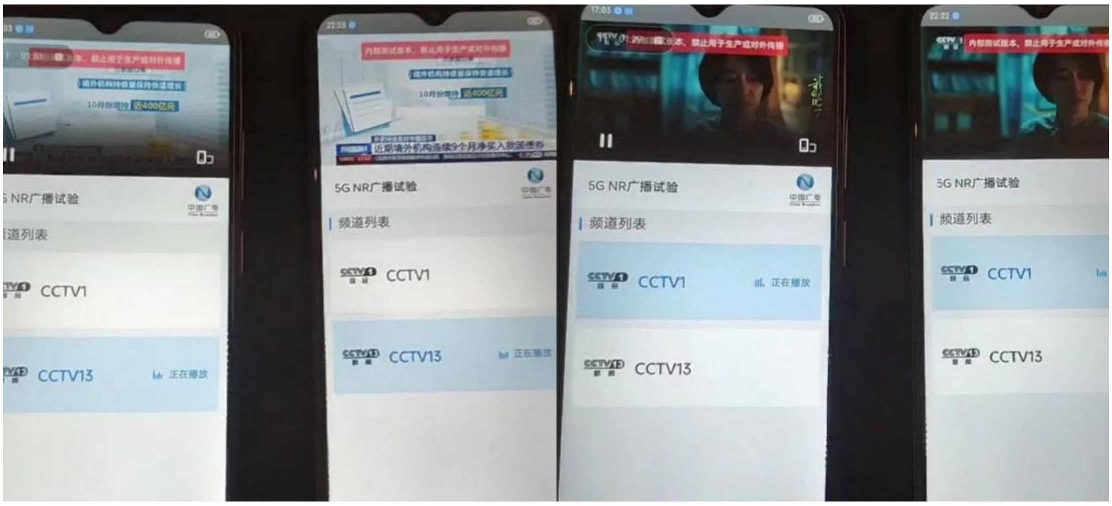
TABLE 21 (*end*)

Test steps:	1 Turn on NR MBS function. 2 Check that the card types of the two terminals are without SIM cards. Turn on the two terminals and connect to the cell. Check the system messages received by the terminals; the Application Server starts broadcast service push. 3 The UE receives the broadcast service from the server through the APP. The APP switches to channel one to check whether the broadcast service is normal and the video definition is normal; the APP switches to channel two and checks whether the broadcast service is normal and the video definition is normal. 4 The core network starts the emergency broadcast push, and the APPs of the two UEs display the emergency broadcast pop-up window. After closing the pop-up window, repeat Step 3. 5 Observe terminal or system PDSCH scheduling information.
Test results:	1 In Step 2, the UE checks that the subCarrierSpacingCommon field in the MIB message carries a value of scs15or60; checks that the IMSI of the SIM card meets the card type requirements, and the card insertion method of the two UEs meets the requirements of no SIM card. Check and record the PLMN, NR SSB frequency point and NR PCI of the cell where the UE is staying to confirm that it is staying on the NR Cell. 2 In Step 3, the two UEs can normally receive the broadcast services issued by the broadcast server, the services are clear and smooth, and the channel switching is successful. 3 In Step 4, the core network successfully pushed the emergency broadcast. The APPs of the two UEs can display the emergency broadcast pop-up window normally. The content of the pop-up window is the same as that of the push. After closing the pop-up window, you can continue to receive the services issued by the broadcast server. The services are clear and smooth, and the channel can be switched successfully. 4 In Step 5, record the RSRP, SNR, MCS, DL MAC rate, PDSCH iBLER and other information of the UE by checking the UElog or system log.

The 5G NR MBS emergency broadcast playback interface is shown in Fig. 58.

FIGURE 58

5G NR MBS emergency broadcast playback

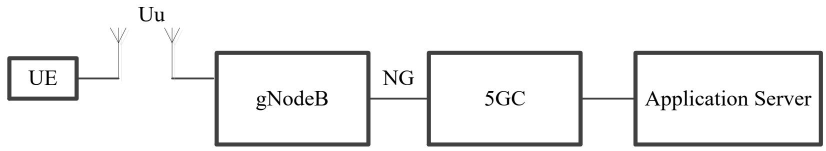


6.3.2.4 5G NR MBS coverage capability test

The 5G NR MBS coverage capability test plan is shown in Table 22.

TABLE 22

5G NR MBS Coverage Capability Test Plan

Testing purposes:	Verify the coverage capabilities of 5G NR MBS.
Networking method:	
Preconditions:	1 gNB, terminal hardware and software are working normally. 2 Use 5G commercial SoC/baseband chip mobile phone terminals for testing. Prepare a test terminal with 700 MHz NR bandwidth capability. The terminal configuration is without SIM card. 3 The Application Server is configured to support streaming video broadcast services. Supported channel video formats are: H.265 encoding, code rate 300 kbit/s, VBR, resolution 720 × 576. 4 The test terminal is pre-installed with the CBN NR MBS APP that supports broadcast services. 5 Prepare a special test vehicle for road testing. There is a suitable test route in the normal direction of the sector coverage and there is no obvious obstruction.
Test steps:	1 The test vehicle performs a mobility test, the vehicle speed is less than 30 km/h, the test route covers the normal direction along the sector, and the terminal is placed in the vehicle without obvious obstruction. 2 The system turns on the NR MBS function. 3 Check that the card type of the terminal is no SIM card, power on the terminal and access the cell, check the system messages received by the terminal, and the Application Server starts broadcast service push. 4 The UE receives the broadcast service of the server through the APP, opens the APP to watch the channel while the test car is traveling, and checks whether the broadcast service is normal and the video clarity is normal. 5 Observe terminal or system scheduling information.
Test Results:	1 In Step 3, the UE checks that the subCarrierSpacingCommon field in the MIB message carries a value of scs15or60; checks that the SIM card meets the card type requirements, and the UE card insertion method is no SIM card. Check and record the GPS information during the test. 2 In Step 4, the UE can normally receive the broadcast service delivered by the broadcast server, and the service is clear and smooth. 3 In Step 5, record the route GPS information and route conditions, RSRP, SNR and other information on the UE side by checking the UE log or system log.

6.4 Conclusion

This contribution verifies the network planning scheme of 5G NR MBS, and the network technical scheme of core network, cellular base station and TV Tower. Taking the network deployment scheme in Beijing as an example, the basic services, emergency broadcast function and coverage ability of

5G NR MBS are verified by using program source, Service ID and other technical means, and the flexible networking mode of one-station dual/multi access of 5G NR MBS core network is realized.

7 Multimedia service trials based on 5G NR MBS in Beijing

7.1 Vehicle audio and video system based on 5G NR MBS

With the development of vehicle intelligence, especially the emergence of a large number of new energy vehicles, traditional audio broadcast receivers are gradually diminishing, and broadcast functions are then realized through networked APPs. However, the problem that arises is that when the vehicle enters an area with no signal coverage, or due to congestion, high traffic volume, etc., causing network jams or even interruption, the broadcast function is inaccessible. In emergencies or during unexpected events, the absence of broadcast function will bring a series of risks to emergency rescue, emergency notices, etc. 5G NR MBS can solve the problem of lack of wireless broadcast module in vehicles by broadcasting, and provide higher quality audio and video services and wider interconnection functions, creating a richer in-vehicle experience for drivers and passengers.

The mobile cellular base station is hung at a height of 22 m, the transmitting antenna is 4T4R, the downtilt angle is 2 degrees, the transmitting power is 120 W, the frequency is 758-763 MHz, and the modulation method is 16-QAM. Other configuration parameters are shown in Table 23.

TABLE 23

Configuration parameters

Index	Parameter
NR frequency	700 MHz band
NR cell bandwidth	5 MHz
PRACH format	Format0
PRACH cycle	10 ms
PUCCH format	Format2
SSB sub-carrier spacing	15 kHz
PBCH cycle	20 ms
Antenna channels	4
Uplink power control	Enable
AMC	Enable
RF module specifications	4T4R
Terminal transmit power	The total power of SA shall not exceed 23 dBm
Business type	5G NR Broadcasting (Audio and Video)
Wireless and terminal transmission	IPv6

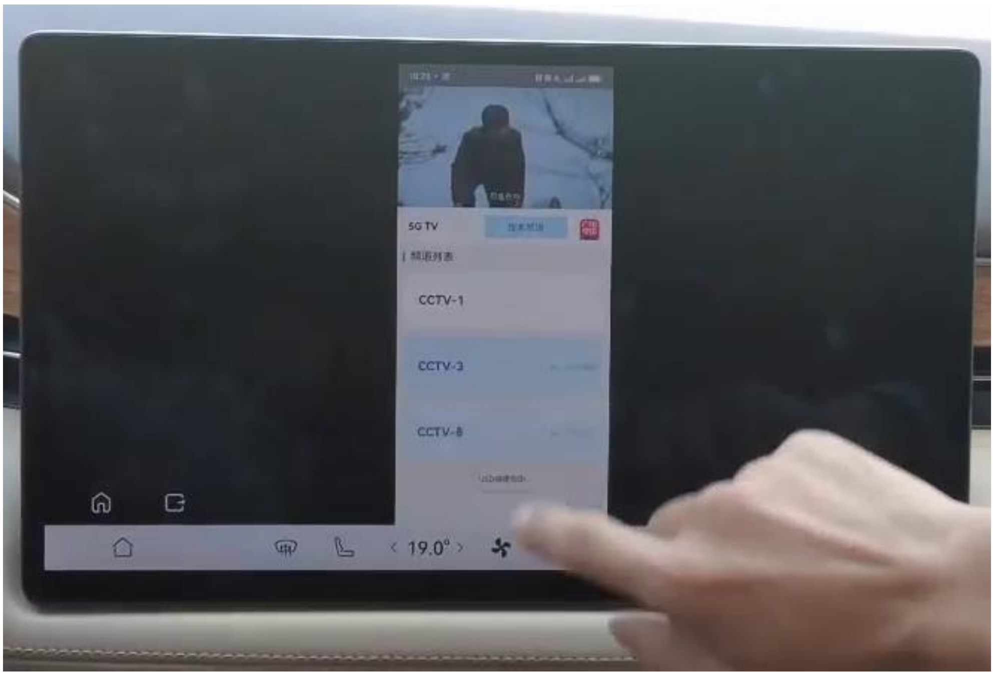
Automotive audio and video systems are electronic devices and systems installed inside the vehicle to provide audio and video entertainment, information, and navigation services. Such systems usually include, but are not limited to, the following components: audio players, video displays, navigation systems, reverse cameras, Internet of vehicle services, etc. The combination of in-vehicle audio and video systems and 5G NR MBS will greatly improve the performance and user experience of in-vehicle media, mainly in the following aspects:

High-speed data transmission: 5G NR MBS utilizes wider spectrum bandwidth and advanced coding technology to provide much faster data transmission speeds than traditional broadcast systems. This means that on-board systems can receive higher resolution video streams and enjoy smoother, lag-free audio and video services.

Multiplexing and concurrent content delivery: 5G NR MBS supports multiplexing and can transmit multiple programmes simultaneously in the same frequency band, which means that in-vehicle audio and video systems can provide a richer selection of programmes, including HD and ultra HD video, multi-language options, real-time news and sports events. 5G NR MBS multiplexing is shown in Fig. 59.

FIGURE 59

5G NR MBS multiplexing

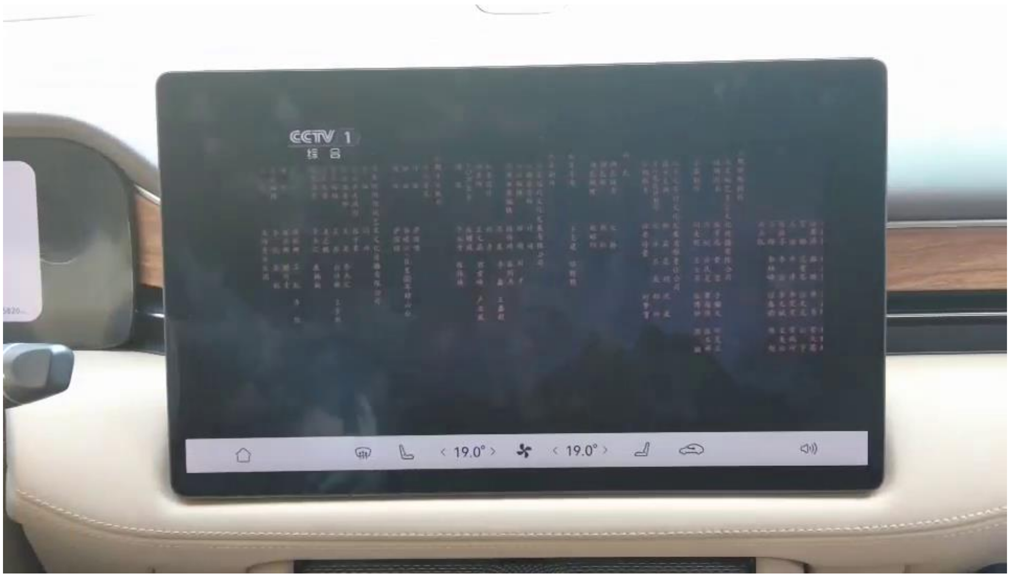


Low latency: The low latency of 5G NR MBS enables in-vehicle audio and video systems to broadcast events in real time, which is particularly important for live content such as sporting events, concerts or live news broadcasts.

High reliability and coverage: 5G NR MBS uses multi-antenna technology (such as MIMO) and beamforming to improve signal stability and coverage, ensuring that high-quality audio and video services are maintained while on the move. The high-quality audio and video usage scenario of 5G NR MBS is shown in Fig. 60.

FIGURE 60

High-quality audio and video broadcasting usage scenario



The audio usage scenario is shown in Fig. 61.

FIGURE 61

Audio broadcasting usage scenario

Intelligent content push: Combined with AI and big data analysis, 5G NR MBS can intelligently push relevant content based on user preferences and location information to provide personalized services.

Augmented Reality (AR) and virtual reality (VR) experiences: The large bandwidth and low latency of 5G NR MBS enable in-vehicle systems to deliver AR and VR content to create immersive entertainment experiences for passengers.

Combined with 5G NR MBS, in-vehicle audio and video systems will become more intelligent, efficient and personalized infotainment platforms, providing drivers and passengers with unprecedented multimedia experiences. With the continuous development of technology, the vehicle audio and video system will continue to iterate and improve, integrate more innovative features to meet the growing needs of users.

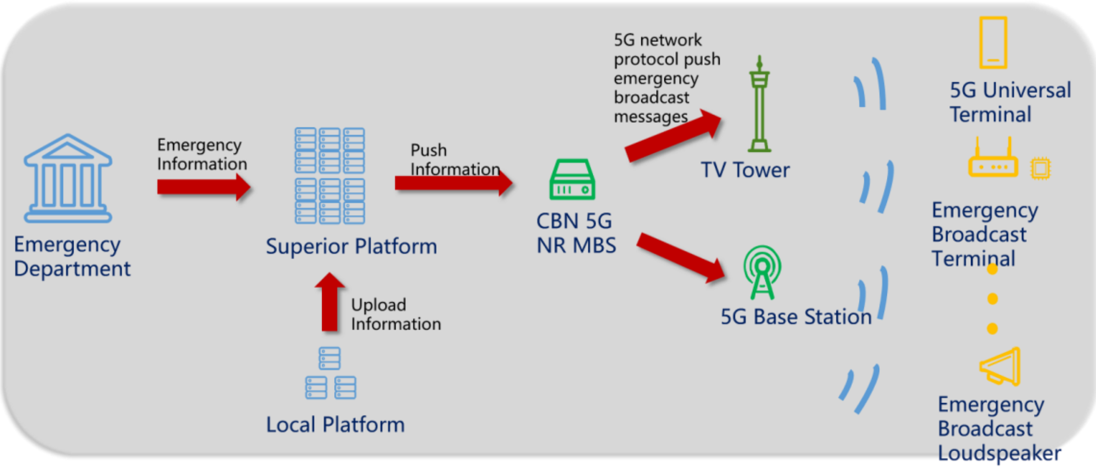
7.2 Emergency broadcast system based on 5G NR MBS

The traditional emergency broadcast transmission network is mainly based on the broadcast network. The public can receive emergency broadcast messages through loudspeakers, radios, television, set-top boxes and other equipment. However, it is easy for people to miss important emergency information because the receiving terminal is not opened or not carried out, and some customized terminals are not high coverage, which cannot ensure people can receive the emergency messages in time. Relying on 5G NR MBS technology, CBN completed the technical docking of the emergency broadcast platform and 5G NR MBS system, applied to the emergency broadcast scenarios, and realizes the broadcast of emergency warning information to the general mobile terminal in the form of video, text, pictures, etc.

Mission Critical (MC) defined by the 3GPP standards organization refers to communication services involving text, voice, and images with low transmission latency, high availability and reliability, the ability to handle large amounts of data, security, and priority processing. In recent years, MC communication and service platforms have been an important priority for 3GPP, and are expected to continue to develop in the future by meeting more needs in different areas of the global critical communications industry. Driven by 3GPP Release, MC-related functions have been implemented in phases across releases, and each version contains a complete set of standards for equipment vendors and operators to implement and deploy in stages according to market demand. The information delivery process is shown in Fig. 62.

FIGURE 62

Information delivery process



In July 2024, CBN completed 5G NR MBS network signal coverage in several villages in Mentougou District, Beijing. The broadcast platform can push emergency warning information to the mobile phone terminal through the 700 MHz network. The administrative divisions of Mentougou and CBN 5G NR base stations in Beijing are shown in Figs 63 to 65.

FIGURE 63

Mentougou administrative division

FIGURE 64

5G NR base station

FIGURE 65

5G NR base station

CBN has developed an APP for in-vehicle business scenarios, taking into account broadcasting business features and operation convenience in on-board conditions, and integrating 5G NR MBS with intelligent transportation systems to provide real-time road conditions, traffic signal information and road construction notifications to improve driving efficiency and safety. The interface of the APP is shown in Fig. 66.

FIGURE 66

Interface of the APP

5G NR MBS traffic emergency reminder is shown in Fig. 67.

FIGURE 67

Traffic emergency alert

The 5G NR MBS natural disaster emergency reminder is shown in Fig. 68.

FIGURE 68

Natural disaster emergency alert

The use of 5G NR MBS to achieve wide coverage of public safety and regional oriented coverage, effectively supplement regional coverage, achieve flexible and scalable coverage of emergency services, comprehensive coverage of signals and pan-terminal, and make up for the lack of broadcast signal coverage.

8 The 5G NR MBS trial in Wuhan

8.1 Overview

5G NR MBS is a mobile multimedia broadcasting system included in Recommendation ITU-R BT.2016. In order to test and verify the technical performance of 5G NR MBS in different scenarios and explore commercial application experience, in November 2024 CBN (China Broadcasting Network) conducted a 5G NR MBS trial in Wuhan, Hubei Province. Wuhan is the capital of Hubei Province, with a total area of 8569.15 km^2 and a population of 13.774 million. Wuhan located in the middle reaches of the Yangtze River, with many rivers and lakes in the city.

This contribution introduces the field test network architecture, test plan and test results of the 5G NR MBS high tower single base station coverage scenario carried out in Wuhan.

8.2 Test network

8.2.1 Overall architecture

5G NR base station was deployed in Wuhan, and broadcasts are pushed through CBN Beijing's core network. End users receive broadcasts in the corresponding frequency band within the coverage of the 5G NR base station signal. At the same time, two signal source laboratories were established in Hubei to upload broadcast sources to AF (Access Facilities).

During the test, multi-time period and multi-path tests were carried out along different directions such as Wuchang and Hanyang, starting from the Wuhan Guishan TV Tower.

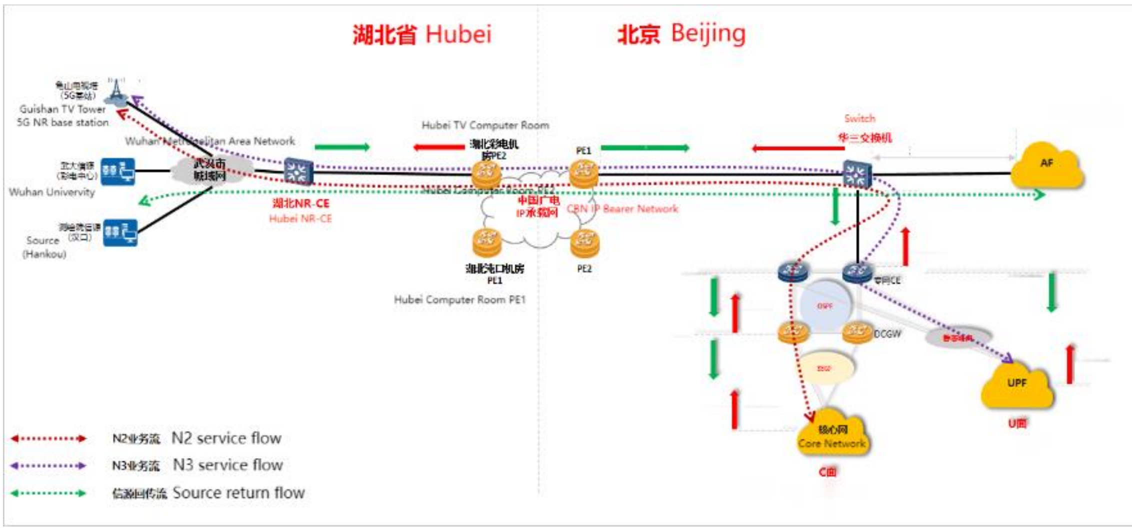
Wuhan Guishan TV Tower was put into use in June 1986. The tower is 221.2 metres high and has a relative height of 280 metres. During the test, the tester held the 5G NR MBS receiving device and observed the reception of multimedia videos in the test vehicle. The test vehicle randomly drove to Wuchang and Hanyang, and the tester recorded the test situation throughout the process.

8.2.2 Data transmission network

Hubei Province has deployed one 5G NR CE (Customer Edge), which is connected to CBN Hubei PE (Provider Edge), and is connected to base stations and information sources through the metropolitan area network. The data network carries the base station and information source backhaul services through two VPNs. Among them, the 5G NR base station used in Hubei is interconnected with the CBN core network through the N2 and N3 interfaces. NR CE connects Hubei's network with the CBN core network and AF's network through static routes, and completes the interconnection between base stations, information sources and NR CE through the city company's L2 VPN within the province. Figure 69 shows the data network architecture in the test.

FIGURE 69

Overall architecture



8.2.3 Base station configuration

In the 5G NR MBS test conducted in Wuhan, a 5G NR base station was installed at the Guishan TV Tower in Wuhan, using the 700 M frequency band, a cell bandwidth of 15 M, and the Hubei TAC of 4 302. Figure 70 shows the Guishan TV Tower, Fig. 71 shows the 5G NR base station, and Fig. 72 shows the location of the base station.

During the test, a single high-tower station was deployed at the Guishan TV Tower. The detailed information of the base station is shown in Table 24.

TABLE 24

Test base station parameters

Base station location	Guishan TV Tower
Latitude and longitude	114.27° E, 30.55° N
Frequency band	758-778 MHz
Carrier bandwidth	15 MHz
Base station transmission power	47.7 dBm
Modulation	QPSK, 16QAM
MCS	4, 15
RANK	1
Antenna high	205 m
Downward tilt	Downward tilt 4 degrees

FIGURE 70

Guishan TV Tower

FIGURE 71

5G NR base station

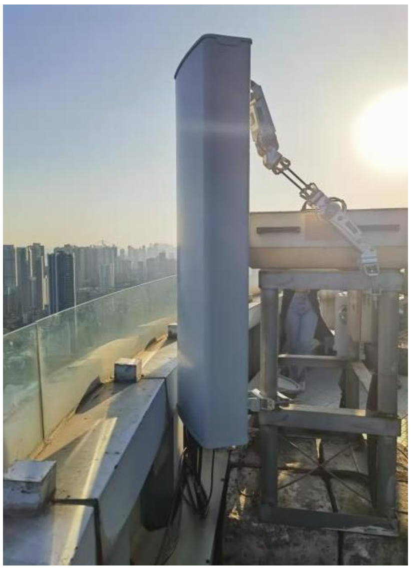
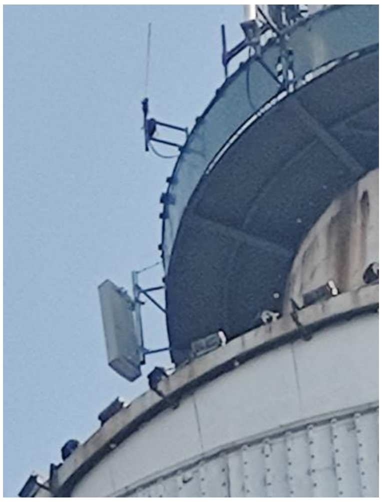


FIGURE 72

The location of the base station on the tower



8.2.4 Test program service flow

A transcoding system is built in the TV tower room, and the video stream is transmitted to the base station using an optical fibre link. The program information is as follows:

The video stream resolution is 1 920 × 1 080, using the H.265 encoding format, the bit rate is 500 kbit/s, and the bit rate is variable.

8.2.5 Test terminal

A Huawei Mate 60 Pro mobile phone (supporting NR MBS version) was used as the test terminal, and a frequency scanner and a drive tester were used to collect information. The detailed information is shown in Table 25.

TABLE 25

Test equipment

	Equipment	Model	Note
1	Mobile phone	Mate 60 Pro	Huawei
2	Frequency scanner	T2318A	Chuangyuan
3	Field test system	Spark1.1.1998.8	Wansiwei

The test terminal is equipped with a 5G NR MBS receiving APP, which can automatically search for programs and support real-time switching. Figure 73 shows the APP interface, and Fig. 74 shows the test device playing the received video and switching the video.

FIGURE 73

APP interface

FIGURE 74

Video playback and switching

8.3 Field test

8.3.1 Test plan

The test takes the Wuhan Guishan TV Tower as the coordinate origin and selects the directions of Wuchang and Hanyang to conduct tests at random times and directions. During the test, the tester held the 5G NR MBS test terminal in the test car, observed the reception effect of China CCTV1 and CCTV13 programmes and recorded the video. The reception effect is divided into three categories in the test:

– The first category: the picture is Jam (indicating no signal).

– The second category: the picture is stuck with mosaics, but it can be played.

– The third category: the picture is smooth without mosaics.

8.3.2 Test data

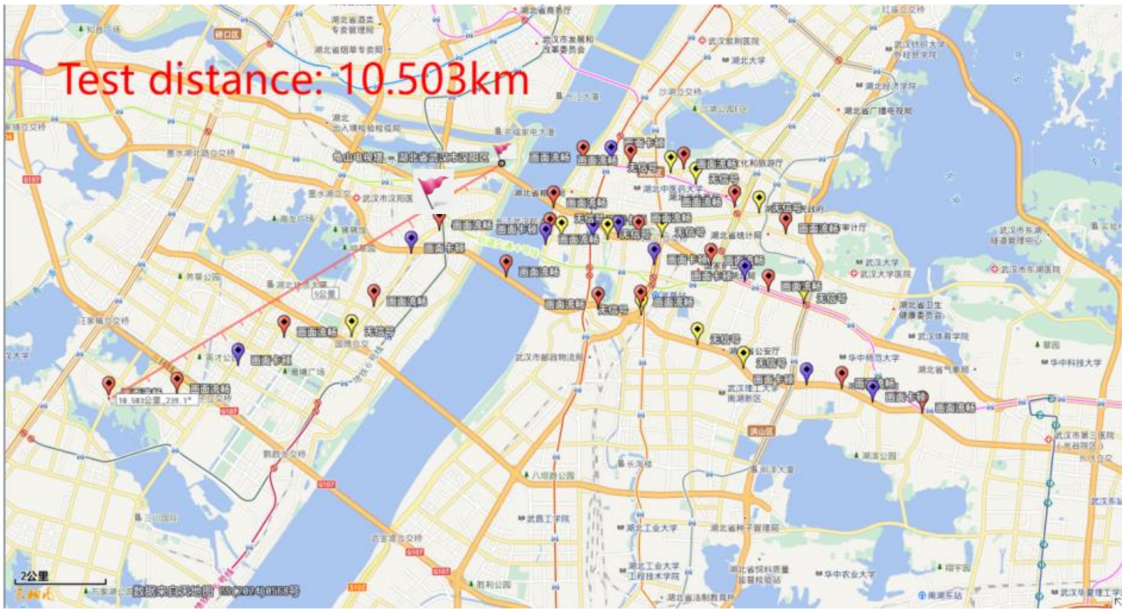
During the test, we selected Hanyang and Wuchang, two densely populated areas in Wuhan, for multiple tests. The test routes and reception conditions are as follows:

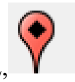
1) Hanyang direction

Hanyang is located southwest of the transmission tower. Figure 75 shows the test point map in the Hanyang direction (the vehicle travels to a maximum distance of 10.50 km from the transmission tower).

FIGURE 75

Test points in the Hanyang direction



NOTES ( : JAM,  : NO SIGNAL,  : SMOOTH,  : GUISHAN TV TOWER)

The test data of Hanyang direction is shown in Table 26.

TABLE 26

Test data of Hanyang direction

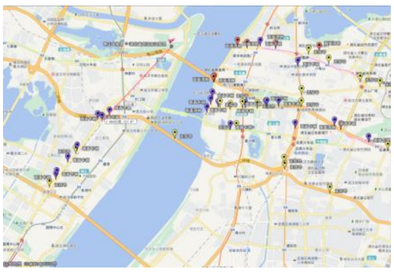
Serial number	Test direction	Test distance/km	Test results	Map	Equipment scene screen
1	Hanyang	1.877	Smooth		 final-smooth6-2.mp4
2	Hanyang	2.884	Smooth		 finalmooth13-1.mp4

TABLE 26 (*end*)

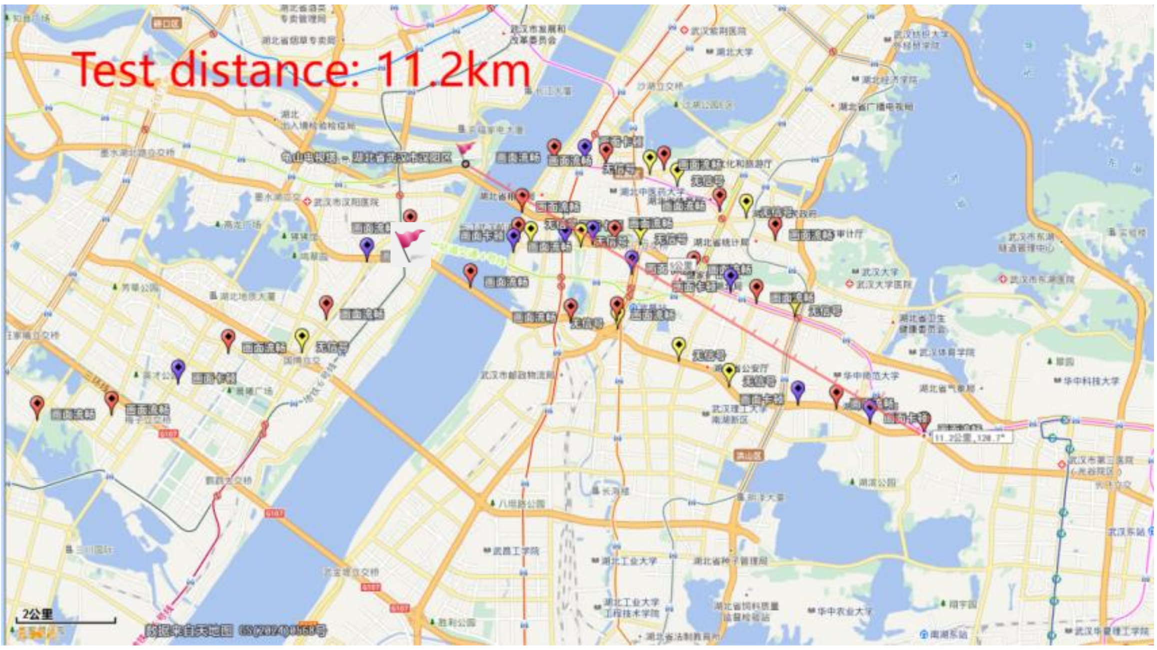
Serial number	Test direction	Test distance/km	Test results	Map	Equipment scene screen
3	Hanyang	2.932	Jam		
4	Hanyang	4.395	Smooth		finalmooth15-1.mp4
5	Hanyang	6.386	Smooth		final-smooth18-2.mp4
6	Hanyang	9.143	Smooth		finalmooth19-1.mp4
7	Hanyang	10.503	Smooth		finalmooth2-1.mp4

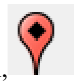
2) Wuchang direction

Wuchang is located southeast of the launch tower. Figure 76 shows the test point map in the Wuchang direction (the vehicle travels to a maximum distance of 11.2 km from the launch tower).

FIGURE 76

Test points in the Wuchang direction



Notes ( : Jam,  : No signal,  : Smooth,  : Guishan TV Tower)

The test data of Wuchang direction is shown in Table 27.

TABLE 27

Test data of Wuchang direction

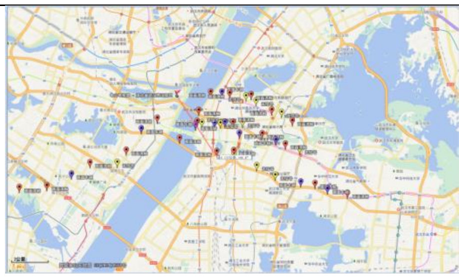
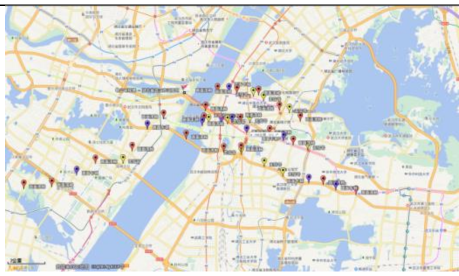
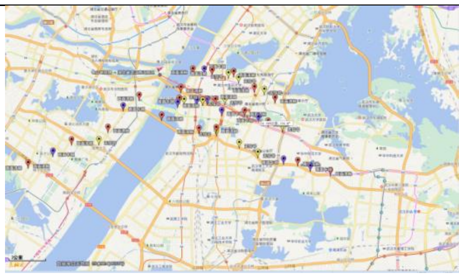
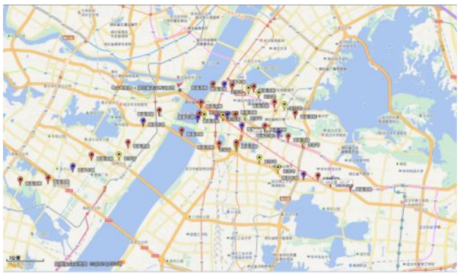
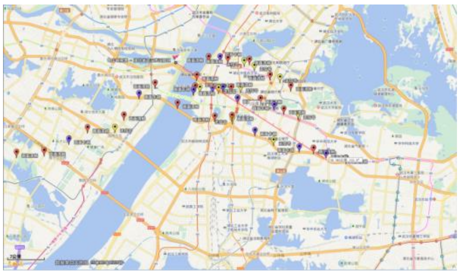
Serial number	Test direction	Test distance/km	Test results	Test points	Equipment scene screen
1	Wuchang	4.137	Smooth		finalmooth3-1.mp4
2	Wuchang	4.196	Jam		
3	Wuchang	5.33	Smooth		final-smooth5-2.mp4
4	Wuchang	6.189	Jam		
5	Wuchang	9.342	Smooth		finalmooth8-1.mp4

TABLE 27 (*end*)

Serial number	Test direction	Test distance/km	Test results	Test points	Equipment scene screen
6	Wuchang	10.102	Jam		
7	Wuchang	11.2	Smooth		 final-smooth9-2.mp4

8.4 Conclusion

The test results of the single base station coverage radius of 5G NR MBS carried out in Wuhan show that: in the southeast direction (Wuchang direction), the test route distance is 11.2 km, and the terminal users receive the data from the broadcast base station stably throughout the process with good signals and smooth received pictures; in the southwest direction (Hanyang direction), the test route distance is 10.5 km, and the terminal users receive the data from the broadcast base station stably throughout the process with good signals and smooth received pictures.

9 The 5G NR MBS Trial in Anhui

9.1 Overview

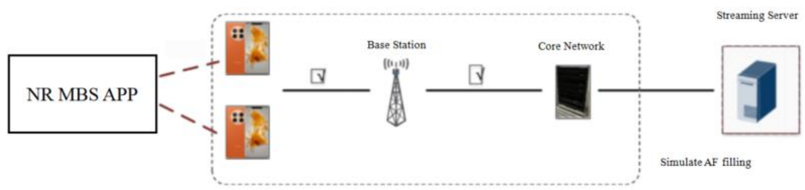
In order to accelerate the commercialization process of 5G NR MBS, in December 2024, CBN conducted 5G NR MBS related tests on the 700 MHz live network in Fuyang, Anhui. Fuyang is located in the northwest of Anhui Province, with a total area of about 10 000 square kilometers. The entire area is plain with flat terrain. The permanent population is about 8 million and the urbanization rate is about 46%.

9.2 Test environment

The test environment and network architecture are shown in Fig. 77.

FIGURE 77

Test architecture



In the test, MBS test AF pushes three channels, CCTV1, CCTV13 and Anhui Satellite TV, with the same video format: HEVC encoding, AAC audio, bit rate 600 kbit/s, resolution 1 920 × 1 080.

9.3 Test parameters

The main parameters in the test are shown in Table 28.

TABLE 28

Typical configuration parameters for 700 MHz test

Item	Value	Note
NR frequency	758~788 MHz	
NR bandwidth	30 MHz	
NR transmit power	240 W (Basic Configuration)	4TR Equipment: 4*60 W
NR frame structure	5 ms	
PRACH format	Format3/Format0	
PRACH和TRS cycle	20 ms	
PUCCH format	Select one of Format0/Format1 At the same time, Select one of Format2/Format3	
SSB Subcarrier spacing	15 kHz	
SSB and reference signal Power boosting	Open	3 dB
SSB number of beams	1 Beam	
PBCH cycle	20 ms	
CSI-RS configuration	Cell level: 2 or 4 ports send 1 beam (the weights of the 4 ports are the same), each beam has 60, 1 beam is sent per scanning cycle, and the scanning cycle is 20 ms	
PDCCH number of beams	Same as SSB	Same number of beams as SSB, common
PDCCH number of symbols	1	If there is any special configuration, it will be described separately in the test case.
Number of antenna channels	2/4TR	
Uplink power control	Enable	PUCCH, PUSCH, Sounding

TABLE 28 (*end*)

Item	Value	Note
AMC	Enable	
Terminal form	SA: 1T2R	
Terminal transmit power	The total power of SA shall not exceed 23 dBm	
Business type	TCP Service	
Wireless and terminal transmission	IPV4 or IPV6	

9.4 5G NR MBS test

During the field trial, 5G NR MBS service mobility, service continuity, service coverage capability and emergency broadcast were tested. Detail information about the test is shown as below.

9.4.1 5G NR MBS service mobility test

9.4.1.1 Test setup

The same-frequency mobility test setup for 5G broadcast service is shown in Table 29.

TABLE 29

Same-frequency mobility test setup

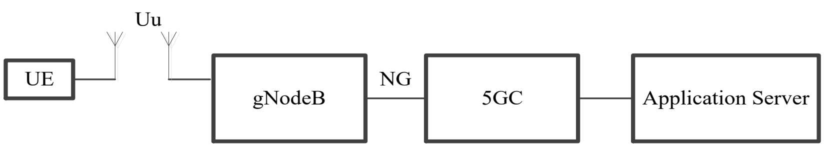
Purpose of the test	Verify the same-frequency mobility of 5G NR MBS services
Networking solution	
Prerequisites	1 The gNB and terminal hardware and software work normally. 2 A mobile phone terminal with a 5G commercial SoC/baseband chip is used for testing. A test terminal with 700 MHz NR bandwidth capability is prepared. The terminal is configured with a mobile card + no card (the mobile card is inserted in card 1). 3 The Application Server is set to support streaming video broadcasting service capabilities. Support channel 1, video format: H.265 encoding, bit rate 300 kbit/s, VBR, resolution 720 × 576; support channel 2, video format: H.265 encoding, bit rate 1 Mbit/s, VBR, resolution 1920 × 1080. 4 The test terminal is pre-installed with an NR multicast broadcast APP that supports broadcast services. 5 The broadcast coverage is aligned with the coverage level of the 700 MHz large network (MCS corresponding to the cell edge). Prepare a dedicated test vehicle for road testing.

TABLE 29 (*end*)

Purpose of the test	**Verify the same-frequency mobility of 5G NR MBS services**
Test steps	Testing of different background load scenarios: 1 Select some lightly loaded sites. 2 Select the test route, which needs to traverse the main and branch roads in the test area. The test vehicle carries the test terminal and traverses the test route at a speed of about 10 km/h to 30 km/h. 3 The system turns on the NR MBS function. 4 The terminal is turned on and connected to the cell, and the system message received on the terminal side is checked; Application Server starts broadcast service push. 5 The UE with the card starts the unicast service. 6 The UE receives the broadcast service of the server through the application APP. When the test vehicle is moving, open the APP to watch channel 1 and check whether the broadcast service is normal and the video clarity; switch the APP to channel 2 to check whether the broadcast service is normal and the video clarity. If the broadcast service cannot be played normally (such as screen freeze, static or black screen, replay program failure, etc.), record the position and corresponding measurement value at this time. 7 The UE with the card checks whether the unicast service is normal during the test vehicle. The live broadcast service needs to check the video clarity. When the unicast service cannot be played normally (such as voice freeze, screen freeze, static or black screen, replay program failure, etc.), record the position and corresponding measurement value at this time. 8 Drive along the planned route until the test route traversal is completed. 9 Observe the scheduling information on the terminal side or the system side. 10 Select some overloaded sites, or use simulated load to load to 80%. 11 Repeat the verification of steps 2 to 9. Mobility test of contiguous networking at different speeds: 1 Find a contiguous test site that meets the vehicle speed of about 50~70 km/h. 2 Repeat 3~10 to verify the mobility verification of contiguous networking. Verify the impact of terminal mobility switching at different MCCH periods: 1 Adjust the MCCH period to the minimum value. 2 Repeat steps 1 to 9.
Expected results	1 In step 3, the UE side checks that the subCarrierSpacingCommon field in the MIB message carries a value of scs 15 or 60. Check and record the PLMN, NR SSB frequency and NR PCI of the cell where the UE resides to confirm that it resides in the NR Cell. 2 In step 5, all UEs can normally receive the broadcast service sent by the broadcast server, the service is clear and smooth, and the channel switching is successful. 3 In step 6, the UE with a card can normally perform unicast services, and the service is clear and smooth. 4 In steps 8/11/13/15, by checking the UE side log or the system side log, record the route GPS information and route conditions, RSRP, SINR, MCS, DL MAC rate and other information on the UE side. Observe whether the MBS reselection and reselection reception process images are clear when the UE switches between cells.
Remark	The test route needs to be analysed based on information such as the physical station location and altitude to select a reasonable route. Verify the impact of different background loads, different MCCH configurations, and different moving speeds on MBS inter-cell mobility.

9.4.1.2 Test results

9.4.1.2.1 Light load scenario test

Select some light load sites, set MBS mcs to 4, select the test route, carry the test terminal on the test vehicle for traversal test, 2 terminals, one UE without card for broadcast service, and one UE with card for unicast video service. Three sets of light load tests are performed at vehicle speeds of about 10 km/h to 30 km/h, about 50~70 km/h, and about 10 km/h to 30 km/h, with the MCCH period set to the minimum value. The test route is shown in Fig. 78.

FIGURE 78

Light load test route

The test results of the light load scenario are shown in Fig. 79:

1) In the light load scenario, the unicast UE has no lag in the low-speed and high-speed traversal on the test route, the video playback is smooth, and the sound is clear.

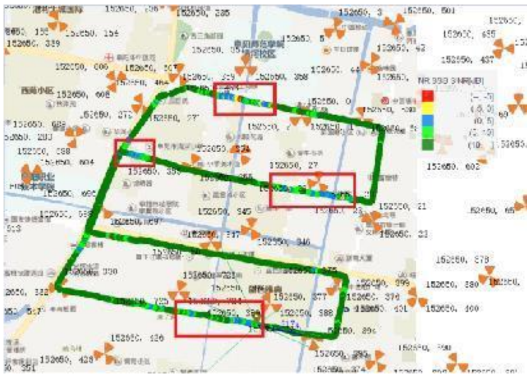
2) In the light load scenario and low-speed broadcast service, the wireless environment is relatively poor, and the SINR is low. After analysing the terminal log of the lag point, it is found that CRC result = 0 accounts for a large proportion.

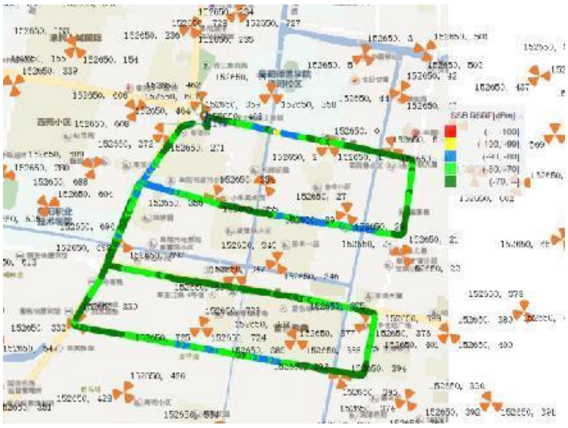
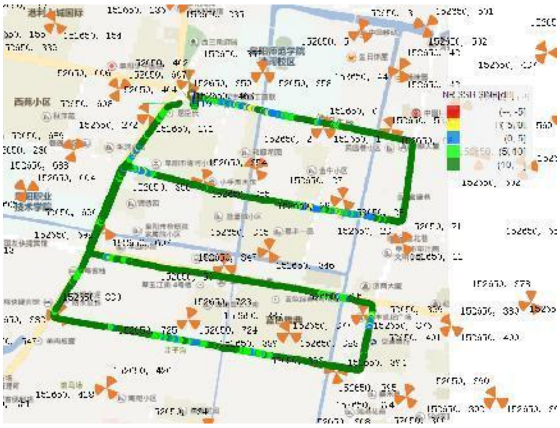
3) In the light load scenario and high-speed broadcast service, the lag points are basically the same.

4) In the light load scenario and low-speed broadcast service, the MCCH cycle is set to the minimum, the lag points are basically the same, the program list needs to be refreshed again. The overall subjective feeling is worse than the low speed effect.

FIGURE 79

Results of light load test route

UE1-Unicast-Low-Speed-RSRP	UE1-Unicast-Low-Speed-SINR
	
UE1-Unicast-Low Speed (Video Playback is Normal)	UE2-Broadcast-Low Speed (with lag)
	
UE1-Unicast-High-Speed-RSRP	UE1-Unicast-High-Speed-SINR
	

UE1-Unicast-High Speed (Video playback is normal)	UE2-Broadcast-High Speed (with lag)
	
UE1-Unicast-Low-Speed-MCCH Setting Minimum-RSRP	UE1-Unicast-Low-Speed-MCCH Setting Minimum-SINR
	
UE1-Unicast-Low-Speed-MCCH is set to minimum (video playback is normal)	UE2-Broadcast-Low Speed-MCCH set to minimum (with lag)
	

9.4.1.2.2 Heavy-load scenario test

The downlink load of all sites on the test route was simulated to be 80%, MBS mcs was set to 4, and the test vehicle carried two test terminals for traversal testing. Two terminals, one UE without a card for broadcast services, and one UE with a card for unicast video services. Two sets of heavy-load tests were conducted at vehicle speeds of about 10 km/h to 30 km/h and 50 to 70 km/h.

The test results of the heavy-load scenario are shown in Fig. 80:

1) In the heavy-load scenario, the unicast UE traversed the test route at low and high speeds without any lag, and the video playback was smooth and the sound was clear.

2) In the heavy-load scenario, it was basically the same as the light-load scenario. There were 4 points with severe and long-term lags on the same route.

3) The heavy-load scenario is basically the same as the light-load scenario. For high-speed broadcast services, the freeze points are basically the same, but there is one long freeze. The location of this problem is different from the light-load scenario. It occurs at the intersection of Xihu Avenue and Yinghuai Avenue. It is normal until the program list is refreshed on Yingnan Road.

FIGURE 80

Results of heavy load test route

Heavy load-UE1-Unicast-Low speed-RSRP

Heavy load-UE1-unicast-low-speed-SINR

Heavy load-UE1-Unicast-Low speed (video playback is normal)

Heavy load-UE2-broadcast-low speed (with lag)

Heavy load-UE1-Unicast-High speed-RSRP	Heavy load-UE1-unicast-high speed-SINR
	
Heavy load-UE1-Unicast-High speed (video playback is normal)	Heavy load-UE2-broadcast-high speed (with lag)
	

9.4.1.3 Test conclusion

1) In the light-load scenario and heavy-load scenario, unicast UE has no lag in low-speed and high-speed traversal on the test route, the video playback is smooth and the sound is clear.

2) In the light-load scenario and heavy-load scenario, and the broadcast service is traversed at low speed, the lag points are basically the same.

3) In the light-load scenario and heavy-load scenario, and the broadcast service is traversed at high speed, the lag points are basically the same, the program list needs to be refreshed again. The point where this problem occurs is inconsistent.

4) In the light-load scenario and the broadcast service is traversed at low speed, the MCCH cycle is set to the minimum, and the lag points are basically the same. The program list needs to be refreshed again.

9.4.2 5G NR MBS service continuity test

9.4.2.1 Test settings

5G NR MBS service continuity test settings are shown in Table 30.

TABLE 30

Service co-frequency continuity test settings

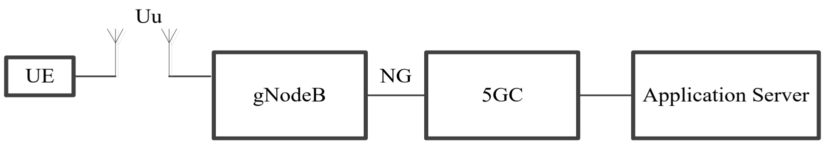
Purpose of the test	**Verifying the co-frequency continuity of 5G NR MBS services**
Networking solution	
Prerequisites	1 The gNB and terminal hardware and software work normally. 2 For mobile terminal testing using 5G commercial SoC/baseband chips, prepare a test terminal with 700 MHz bandwidth capability, and configure the terminal with a mobile card + no card (the mobile card is inserted in card 1). 3 Under the SA network architecture, the two NR cells CELL1 and CELL2 work normally, with a working frequency band of 700 MHz and a configured bandwidth of 30 M; the two cells are configured with co-frequency neighbouring cells. 4 The Application Server is set to support streaming video broadcasting service capabilities, support channel 1, video format: H.265 encoding, bit rate 300 kbit/s, VBR, resolution 720 × 576; support channel 2, video format: H.265 encoding, bit rate 1 Mbit/s, VBR, resolution 1920 × 1080. The test terminal is pre-installed with an NR multicast broadcast APP that supports broadcast services.
Test steps	1 The system turns on the NR MBS function. 2 The UE status is no card, the UE is turned on in CELL1, and the system message received on the UE side is checked; Application Server starts broadcast service push. 3 The UE receives the broadcast service of the server through the application APP, opens the APP to watch channel 1, and checks whether the broadcast service is normal and the video clarity; the APP switches to channel 2, and checks whether the broadcast service is normal and the video clarity. 4 The UE moves to CELL2, repeats step 3, checks whether the broadcast service is normal and the video clarity, and observes whether the service is interrupted. 5 Observe the scheduling information on the UE side or the system side. 6 Insert the SIM card of China Mobile on the UE side (dual-card UE needs to insert 2 cards), the UE is turned on and resides in CELL1 and remains in IDLE state, and the system message received on the UE side is checked; Application Server starts broadcast service push. 7 The terminal receives the server's broadcast service through the application APP, opens the APP to watch channel 1, and checks whether the broadcast service is normal and the video clarity; the APP switches to channel 2, and checks whether the broadcast service is normal and the video clarity. 8 The UE reselects CELL2, repeats step 3, checks whether the broadcast service is normal and the video clarity, and observes whether the service is interrupted. 9 Observe the scheduling information on the UE side or the system side. The UE turns on and connects to CELL1 and maintains the CONNECTED state, repeating steps 2 to 5 (step 4 is for the UE to switch to CELL2).

TABLE 30 (*end*)

Purpose of the test	**Verifying the co-frequency continuity of 5G NR MBS services**
Expected results	1 In step 3, the terminal side checks that the subCarrierSpacingCommon field in the MIB message carries a value of scs 15 or 60; checks that the SIM card IMSI meets the card type requirements, and the UE card insertion mode is without a card. Check and record the PLMN, NR SSB frequency and NR PCI of the cell where the terminal resides to confirm that it resides in the NR Cell. 2 In step 3, the terminal can normally receive the broadcast service sent by the broadcast server, the service is clear and smooth, and the channel switching is successful. 3 In step 4, the service interruption time in the IDLE state and the CONNECTED state is recorded respectively. In step 5, by checking the terminal side log or the system side log, the route GPS information and route conditions, RSRP, SINR, MCS, DL MAC rate and other information on the terminal side are recorded.
Remark	The test route needs to be analysed based on information such as the location and altitude of the physical station to select a reasonable route.

9.4.2.2 Test results

The cardless mobility test route is shown in Fig. 81. The cardless mobility test-MBS broadcast continuous coverage area, the switching is normal, and the terminals can receive the broadcast message, but the video at the station is stuck, and it will recover after manual refresh. The test results are shown in Fig. 82.

FIGURE 81

Card-less mobility test route

FIGURE 82

Card-less mobility test results

370 cell access, video playback is normal	Video card disconnection occurs at the station	After refreshing, the video plays normally
		

9.4.2.3 Test conclusion

1) The broadcast terminal can normally enter the MBS APP and play videos, and can normally switch between two cells.

2) The terminal is turned on and stays in the cell and remains connected. While the broadcast APP is searching for programs, the SIM card is disabled, resulting in the inability to maintain the connection state.

9.4.3 5G NR MBS service coverage capability test

9.4.3.1 Test settings

5G NR MBS service coverage capability test settings are shown in Table 31.

TABLE 31

Service coverage capability test settings

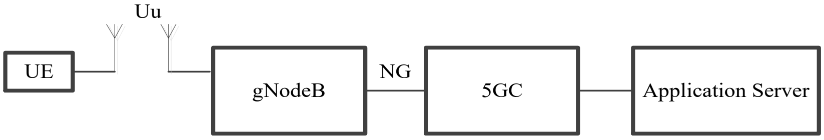
Purpose of the test	**Verify the coverage capability of 5G NR MBS services and compare the coverage capability of 5G NR MBS services with that of unicast services**
Networking solution	

TABLE 31 (*end*)

Purpose of the test	**Verify the coverage capability of 5G NR MBS services and compare the coverage capability of 5G NR MBS services with that of unicast services**
Prerequisites	1 The gNB and terminal hardware and software work normally. 2 For mobile terminal testing using 5G commercial SoC/baseband chips, prepare three test terminals UE1, UE2, and UE3. UE1 and UE2 have 700 MHz NR bandwidth capabilities, and the terminal configuration is cardless. 3 The Application Server is set to support streaming video broadcasting service capabilities. Supported channel video formats are H.265 encoding, bit rate 300 kbit/s, VBR, resolution 720 × 576. 4 UE1 and UE2 pre-install broadcast APP that supports 5G NR MBS. Prepare a dedicated test vehicle for road testing. There is a suitable test route in the normal direction of sector coverage without obvious obstruction:
Test steps	1 Test vehicle mobility test, vehicle speed is less than 30 km/h, test route is along the sector covering normal direction, three terminals are placed in the vehicle, no obvious obstruction. 2 The system turns on the NR broadcast function, UE1 and UE2 receive NR broadcast services; UE3 receives real-time live video as a unicast service. 3 Check that the card type of UE1 and UE2 is not card-free, the 3 UEs are turned on to access the cell, and check the system messages received by the UE. Application Server starts service push. 4 The test vehicle carries three UEs, starts from the base station, and drives along the route to the edge of the cell. The terminal receives the broadcast and unicast services of the server through the application APP. During the driving process of the test vehicle, check whether the service is normal and the video clarity, until the broadcast service and real-time live video cannot be played normally (such as static or black screen, replay programme fails, etc.), record the position of UE1, UE2, and UE3 at this time and the corresponding measurement values (RSRP, SINR). 5 Record the corresponding scheduling information and data on the UE side and the base station side. UE1 and UE2 insert China Mobile's SIM card (dual-card UE needs to insert two cards) and repeat steps 3~5.
Expected results	1 In step 3, UE1 and UE2 check that the subCarrierSpacingCommon field in the MIB message carries a value of scs 15 or 60; check that the SIM card meets the card type requirements, and that the card insertion method of UE1 and UE2 meets the cardless state. Check and record the GPS information of the three terminals during the test. 2 In step 4, UE1 and UE2 can normally receive the broadcast service sent by the broadcast server, and UE3 can normally receive the real-time live video, and the service is clear and smooth; compare the service reception range of the three terminals. In step 5, by checking the UE side log or the system side log, record the route GPS information and route conditions, RSRP, SNR and other information on the UE side.
Remark	

9.4.3.2 Test results

The Zhangxiaozhuang-1538226 (PCI667) cell in Shierli Temple was selected to test the broadcast service coverage capability. The test route is shown in Fig. 83.

FIGURE 83

Service coverage capability test route

To reduce the interference of the test cell, the surrounding interference cells are turned off.

Three terminals, UE1 and UE2 without card receive NR broadcast services; UE3 with card receives real-time live video as unicast service, and the distance test is carried out along the normal direction of sector coverage with a vehicle speed of less than 30 km/h. The test results are shown in Fig. 84.

UE1 and UE2 can normally receive the broadcast service sent by the broadcast server, and UE3 can normally receive real-time live video, and the service is clear and smooth.

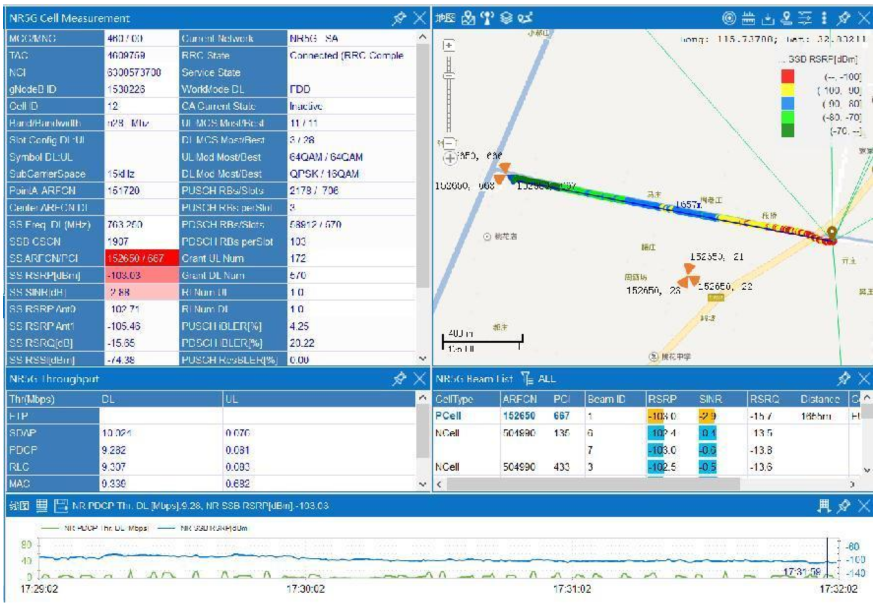
FIGURE 84

Service coverage test results

When UE1 and UE2 cannot broadcast, they are 1.66 km away from the base station, where RSRP is −105.1 dBm and SINR is −2.5 dB, as shown in Fig. 85.

FIGURE 85

Field strength distribution of service coverage test



The test site environment is shown in Fig. 86.

FIGURE 86

Test site

9.4.3.3 Test conclusion

1) UE1 and UE2 can normally receive the broadcast service sent by the broadcast server, and UE3 can normally receive real-time live video, and the service is clear and smooth.

2) When UE1 and UE2 cannot play the broadcast, they are 1.66 km away from the base station, where RSRP is −105.1 dBm and SINR is −2.5 dB. At this time, the unicast video service is clear and smooth. The reason is that the fixed MCS of the broadcast service is 4, and the MCS of the unicast service can be adjusted adaptively. It can be seen from the test point that the downlink MCS of the unicast service is 3 at this time.

3) UE1 and UE2 are plugged into China Mobile's SIM card (dual-card UE needs to insert two cards), and the single-card test is turned on. It is needed to select "Search All" to get the result.

9.4.4 5G NR MBS emergency broadcast

9.4.4.1 Test settings

5G NR MBS emergency broadcast test settings are shown in Table 32.

TABLE 32

Emergency broadcast test settings

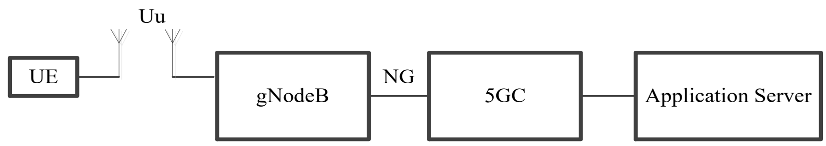
Purpose of the test	**5G NR MBS supports emergency broadcasting function**
Networking solution	
Prerequisites	1 The gNB and terminal hardware and software work normally. 2 For mobile terminal testing using 5G commercial SoC/baseband chips, prepare two test terminals with 700 MHz NR bandwidth capability, and configure the 2 terminals without cards respectively. 3 The Application Server is set to support streaming video broadcasting service capabilities; support channel 1, video format: H.265 encoding, bit rate 300 kbit/s, VBR, resolution 720 × 576; support channel 2, video format: H.265 encoding, bit rate 1 Mbit/s, VBR, resolution 1 920 × 1 080. 4 The core network supports emergency broadcast push function, and the APP supports emergency broadcast pop-up function. The test terminal is pre-installed with NR multicast broadcast APP that supports broadcast services.
Test steps	1 The system turns on the NR MBS function. 2 Check that the card status of the two terminals is no card, and the two terminals are turned on to access the cell, check the system messages received by the terminal side; Application Server starts broadcast service push. 3 UE receives the server's broadcast service through the application APP, the APP switches to channel 1, checks whether the broadcast service is normal and the video clarity; the APP switches to channel 2, checks whether the broadcast service is normal and the video clarity. The core network starts an emergency broadcast push, the APP of the two UEs displays an emergency broadcast pop-up window. After closing the pop-up window, repeat step 3.

TABLE 32 (*end*)

Purpose of the test	**5G NR MBS supports emergency broadcasting function**
Expected results	1 In step 2, the UE side checks that the subCarrierSpacingCommon field in the MIB message carries a value of scs 15 or 60; checks that the SIM card IMSI meets the card type requirements, and the two UE card insertion methods meet the cardless requirements. checks and records the PLMN, NR SSB frequency and NR PCI of the cell where the UE resides to confirm that it resides in the NR Cell. 2 In step 3, the two UEs can normally receive the broadcast service sent by the broadcast server, the service is clear and smooth, and the channel switching is successful. In step 4, the core network successfully pushes the emergency broadcast, and the APP of the two UEs can normally display the emergency broadcast pop-up window, the pop-up window content is the same as the push, and after closing the pop-up window, it can continue to receive the service sent by the broadcast server, the service is clear and smooth, and the channel switching is successful.
Remark	

9.4.4.2 Test results

The UE side checks that the subCarrierSpacingCommon field in the MIB message carries a value of scs 15 or 60.

The emergency broadcast is pushed successfully, and the APPs of the two UEs can display the emergency broadcast pop-up window normally. The pop-up window content is the same as the push. Before and after closing the pop-up window, the services sent by the broadcast server can be received. The services are clear and smooth, and the channel switching is successful, as shown in Fig. 87.

FIGURE 87

Emergency broadcast test results

Before starting emergency broadcast – Channel 1

Before starting emergency broadcast – Channel 2

Start emergency broadcast-UE1

Start emergency broadcast-UE2

After starting emergency broadcast – Channel 1

After starting emergency broadcast – Channel 2

9.4.4.3 Test conclusion

1 Before the emergency broadcast is pushed, the two UEs can normally receive the broadcast service sent by the broadcast server, the service is clear and smooth, and the channel switching is successful.

2 After the emergency broadcast is pushed successfully, the APP of the two UEs can normally display the emergency broadcast pop-up window, and the pop-up window content is the same as the push. After closing the pop-up window, the service sent by the broadcast server can continue to be received. The service is clear and smooth, and the channel switching is successful.

Annex 2

LTE-based 5G terrestrial broadcast of the Eurovision Song Contest 2022

1 Summary

An LTE-based 5G broadcast signal was transmitted during the Eurovision Song Contest 2022 event live and in high quality from sites in four European cities simultaneously. For now, only a select group of users with LTE-based 5G broadcast-enabled smartphones in Paris, Stuttgart, Turin, Vienna was able to see these transmissions. The aim is to change that, and to demonstrate, with those transmissions, the value this technology could bring to the media and millions of audience members.

LTE-based 5G broadcast is a complementary distribution technology that can add value in a number of use-cases – one of which is access to live content for mass audiences on the go, with the possibility to receive free-to-air content even without a SIM card, no need to sign up to third-party services, and in a way that delivers efficiency gains for distribution infrastructures.

For the purposes of the 2022 ESC LTE-based 5G broadcast trials, the EBU and its members (SWR (Stuttgart), ORS Group (Vienna), France Télévisions (Paris) and RAI (Turin)) teamed up with Eurovision services for the ESC signal logistics, Ateme for the encoding and streaming, Rohde & Schwarz for the transmission equipment, and Qualcomm for the prototype LTE-based 5G broadcast-compatible handsets.

1.1 Participants

– Ateme
– Qualcomm
– SWR (www.swr.de) – EBU member
– ORS/ORF (http://ors.at) (https://orf.at) – EBU member
– RAI (www.rai.it) – EBU member
– France Télévisions (www.france.tv) – EBU member
– Rohde & Schwarz (https://www.rohde-schwarz.com/ca/home_48230.html).

1.2 Start date and duration

– April/May 2022.

1.3 Location

– Geneva
– Paris
– Stuttgart
– Turin
– Vienna.

1.4 Technologies

– 3GPP Release 16 feature set.

1.5 Equipment and infrastructure

– Transmission equipment varied, depending on test-bed location

– Prototype LTE-based 5G broadcast-compatible handsets.

1.6 Spectrum and frequencies

– 600 MHz band – frequencies varied, depending on the test-bed location.

FIGURE 88

Eurovision Song Contest LTE-based 5G broadcast trials

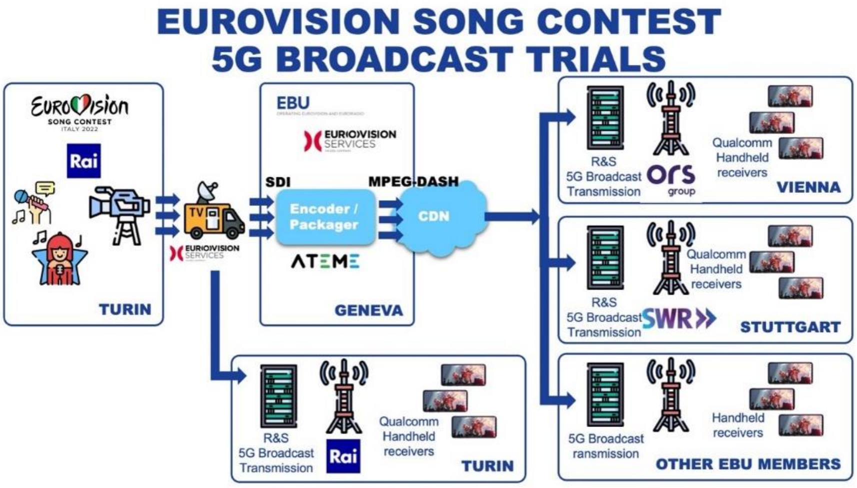


Figure 88 shows the diagram of the setup for the Eurovision Song Contest 5G broadcast trials involving the four sites. The signal was produced by RAI and delivered to the Eurovision Services headquarters in Geneva. A video encoder from Ateme was providing the signal to a CDN end-point where ORS, SWR and France TV were able to retransmit the signal to handsets using the LTE-based 5G Terrestrial Broadcast system.

FIGURE 89

A select group of users with compatible handsets in four cities was able to receive the LTE-based 5G Terrestrial Broadcast signal of the ESC 2022 live

2 Laboratory tests and field trials by Rai-CRITS in Turin

Over the last few years, Rai-CRITS has carried out extensive laboratory tests and field trials on LTE based 5G Broadcast functionalities (defined in Release 14 [1] and Release 16 [2]) to mobile devices, evaluating the coverage and quality of experience (QoE) in urban/dense urban and suburban environments. In particular, Rai successfully tested the LTE-based 5G Broadcast technology within the coverage of the metropolitan area of Turin with a single transmitter. Road measurement tests in both areas have been carried out to collect data about the achievable coverage and the required network configurations to guarantee a satisfactory quality of service (QoS).

The tests in the metropolitan area of Turin allowed an evaluation of the system's performance in a densely populated area characterized by the presence of tall buildings and other obstacles which often prevent a receiver from having the direct view of the transmitting site. The tests also concerned the Turin ring motorway, allowing the evaluation of the LTE-based 5G Broadcast's performance at rather high speeds.

2.1 Laboratory tests

Very extensive lab sessions allowed to gain a first-hand experience of the enormous potential of the system and to understand how mature the technology is for its rapid exploitation. The receiver tested during the laboratory session is the Software Defined Radio (SDR) receiver by Rohde & Schwarz. Different performance evaluations have been conducted for characterising the 'goodness' of both the technology and its implementation, such as the performance in presence of Additive White Gaussian Noise (AWGN) and the performance in case of a 0-dB echo channel to evaluate the resilience of the system in terms of reflections and SFN robustness. Finally, the performance within a mobile channel at different speeds (profile COST207-Typical Urban [3]) have been evaluated.

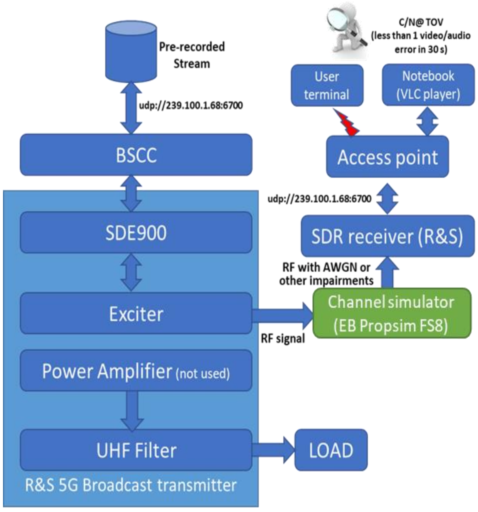
The block diagram of the adopted test bench is reported in Fig. 90. Alongside the classic laboratory equipment used for RF measurements (e.g. attenuators, bolometers), the fundamental devices used during the measurement session were the following:

– Spectrum analyser: Agilent E4443A
– Channel simulator: EB Propsim FS8.

The measurement procedure adopted in all the tests carried out was to add up the selected degradation (AWGN, echoes, Doppler shift, etc.) and to observe the video until reaching the threshold of visibility (TOV), which corresponds to less than one video/audio error in 30 s.

FIGURE 90

Laboratory Set-Up

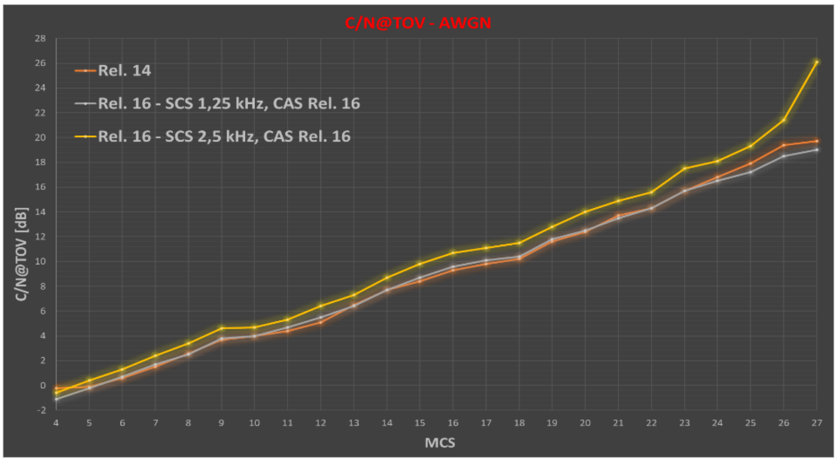


A huge amount of data has been collected during the lab tests. In this Report, only the results which can be considered as preparatory for the subsequent tests in a real service area are shown.

The performance of LTE-based 5G Broadcast in terms of *C*/*N* at the TOV are shown in Fig. 91. The obtained values are quite in line with what is expected from a theoretical point of view, with a limited implementation margin, especially for the more robust MCSs.

FIGURE 91

Additive White Gaussian Noise test results



More in details:

– With a Subcarrier Spacing (SCS) of 1.25 kHz, the results are in line with what has been already found in a previous measurement campaign based on former Release 14 of the standard; these data were already aligned with the expected theoretical ones.

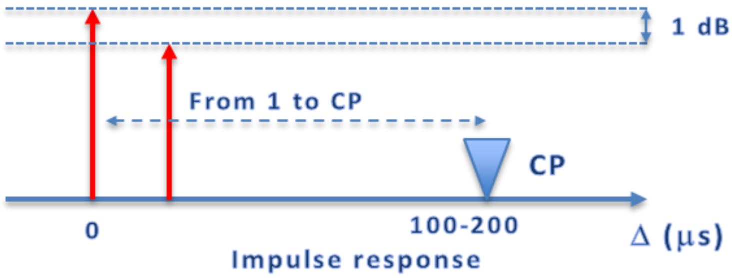
– With a SCS of 2.5 kHz, a slight degradation has been observed ranging from 0.5 dB using the most robust MCS up to about 2 dB with the most efficient MCS.

The "0 dB echo test" has been used to evaluate the robustness of the system in presence of an echo which can be either natural (reflection against an obstacle) or artificial (signal coming from another transmitter operating at the same frequency, SFN). Typically, a "robust" echo (equal to or slightly below the main signal) causes a degradation in performance compared to the presence of AWGN only; this degradation can be quantified between a few dB fractions and a few dBs as long as the delay is within the cyclic prefix (CP). Outside the cyclic prefix, on the other hand, the echo behaves as an interference, thus making the system quickly to collapse.

During these tests, the echo delay, having a power of 1 dB lower than the main signal (*C*/*I* = 1 dB), has been varied from 1 µs up to over the CP (see Fig. 92): 100 µs for SCS = 2.5 kHz, 200 µs for SCS = 1.25 kHz.

FIGURE 92

Impulse response for "Single echo test"



For each delay, noise was added until reaching the TOV. The results for MCS12, reported in Fig. 93, indicate that the behaviour of the receiver, was generally in line with what is theoretically expected. The following observations can also be made:

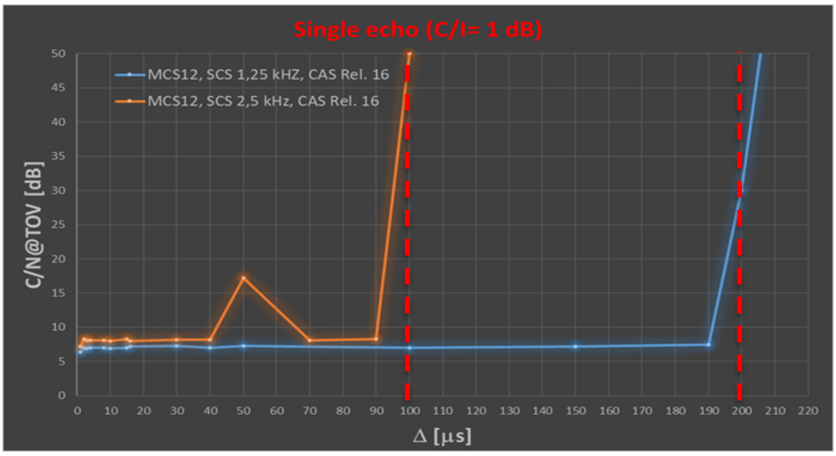
– With SCS = 1.25 kHz the results are in line with what expected (unsynced receiver at about 200 µs).

– With SCS = 2.5 kHz the results are in line with what expected (unsynced receiver at about 100 µs).

– New CAS defined in Rel-16 do not introduce any appreciable differences compared to those of Rel-14.

FIGURE 93

"Single echo test" results for MCS12

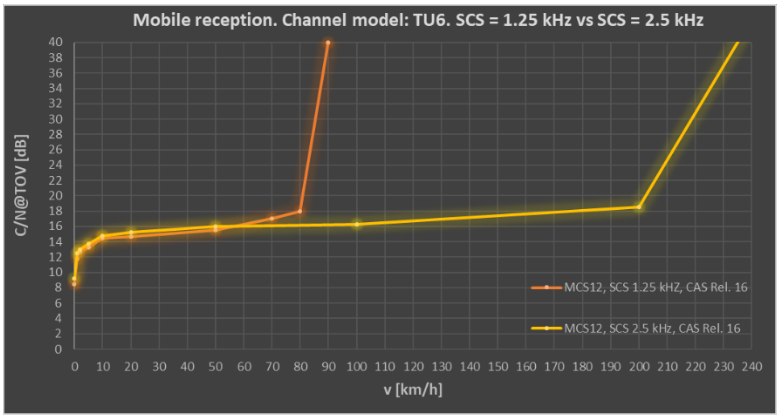


Other laboratory tests simulating the mobile channel aimed at verifying the maximum speed achievable by the system without compromising the reception. Echo profiles, typical of a mobile outdoor reception, have been generated using a channel simulator. These profiles are defined in COST 207: in the tests, a six-echoes profile representing a Typical Urban scenario (TU6) has been used.

The graphic in Fig. 94 reports the estimated *C*/*N* at TOV versus speed in km/h for the UHF channel 53 (f = 730 MHz), which is the test frequency generally used for Rai field trials in the Aosta Valley.

FIGURE 94

Mobile reception performance, TU6



Taking into account that the receiver was not specifically designed for the mobile channel, the results in the labs looked promising. In particular, the maximum achieved speed at 730 MHz was around 80 km/h with SCS = 1.25 kHz and about 200 km/h with SCS = 2.5 kHz, acceptable for most mobile use cases.

Using SCS = 2.5 kHz seems to be the best compromise between robustness against the Doppler effect and the length of the CP (100 µs, for an ISD between transmitters of up to 30 km).

2.2 Field tests

Road measurements with an omnidirectional antenna mounted on the top of the van in the area around Turin have been carried out to collect data about the achievable coverage and the required network configurations to ensure the service, to record the RF signal in different conditions for off-line evaluations on the mobile reception availability, to evaluate the electromagnetic field (EMF) availability and to identify an operating "threshold" for the mobile reception.

To obtain these results, a van was equipped with the following instruments:

– LTE-based 5G Broadcast receiver: Rohde & Schwarz SDR receiver;

– RF recorder: Lumantek Weiver 2.0;

– receiving antenna positioned on the top of the van;

– GPS antennas for georeferencing of measurements;

– monitors positioned in the headrests for observation of the received video;

– notebook with software designed by Rai CRITS for error detection and data logging of the EMF, van speed and geographical position.

The modulation parameters used during these measurement campaigns are based on the results of the preliminary laboratory tests and are a trade-off between the required robustness in a mobile reception context and the available capacity. Table 33 shows the transmission parameters adopted and the frequencies used in the testbed.

TABLE 33

Transmission parameters

Transmission parameters – Turin test bed	
Modulation scheme	MCS12 (16-QAM, rate 0.42)
Subcarrier spacing (SCS)	1.25 kHz (cyclic prefix = 100 µs)
Bandwidth	5 MHz
CAS	Release 16
Available bit rate	4.83 Mbit/s
Frequency	VHF ch. 11 (CF = 219.5 MHz)

2.2.1 Turin testbed

In October 2021, Rai CRITS activated an LTE-based 5G Broadcast Rel. 16 testbed in Turin on VHF channel 11 (f = 219.5 MHz) in vertical polarization. Despite this is not in the typical frequency range addressed for future LTE-based 5G Broadcast services, channel 11 was the only available experimental frequency in the Turin area. However, the reliability of the experiment was not compromised.

The set-up included the activation of one transmitter (see parameters in Table 34) at about 6 km in line of sight from the city centre. A pre-recorded signal has been played in the Rai Production Centre premises of Turin (CPTO). The SDI signal coming from the playout has been used to feed an encoder generating a Transport Stream over IP (TsoIP) at a desired bit rate. The multicast IP has been sent to the transmitting site via an optical fibre connection. At the transmitting site both the Broadcast Service and Control Centre (BSCC) and the transmitting chain by Rohde & Schwarz have been placed. The set-up of the testbed is reported in Fig. 95.

FIGURE 95

Turin testbed set-up

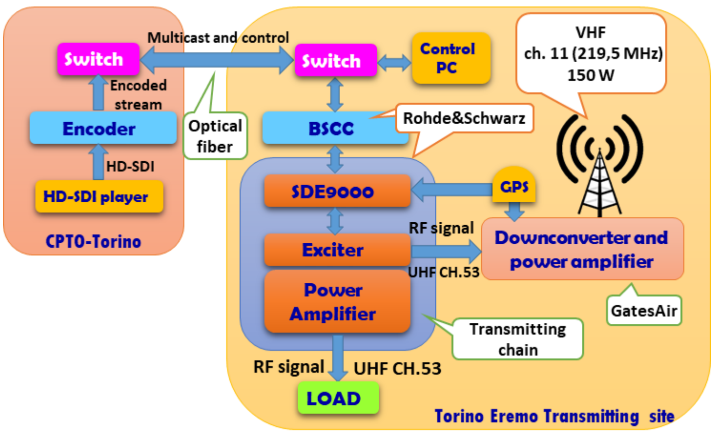


TABLE 34

Turin site parameters

Transmitter	Coordinates	Height	Frequency (CF)	Pout
Torino-Eremo	45°02'30''N – 7°44'08'' E	626 m (asl[1]) – 400 m (agl[2])	219.5 MHz (ch. 11)	150 W

(1) Above sea level.

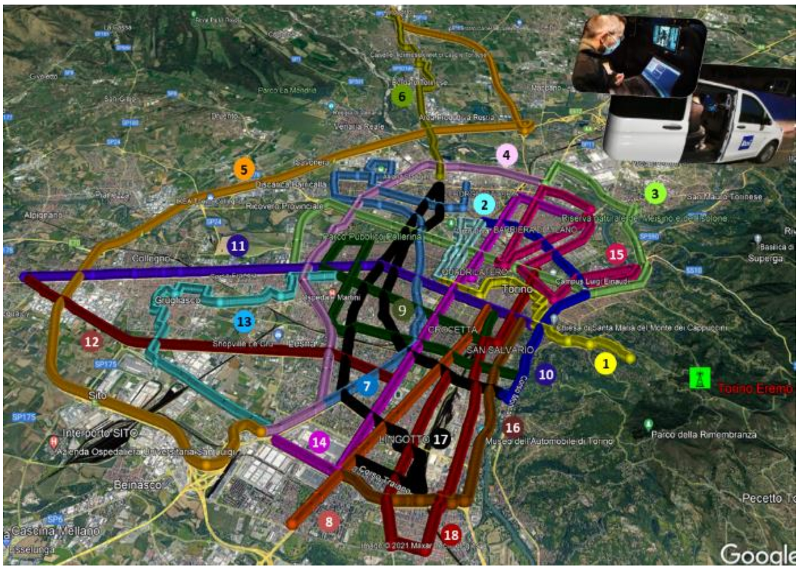
(2) Above ground level (Torino city).

The measurements, mainly carried out in the night to avoid the city traffic, have been divided into "routes" including both the urban and suburban parts of the Turin area, trying to include the most significant and popular places (city centre, airport, stadiums, railway stations, ring road, etc.). This way, 18 routes have been identified for a total of almost 250 km travelled, as illustrated in Fig. 96.

The post-processing of all this huge amount of acquired data made it possible to evaluate the available coverage of the LTE-based 5G Broadcast service transmitted from the Torino – Eremo site.

FIGURE 96

LTE-based 5G Broadcast "subway" in Turin

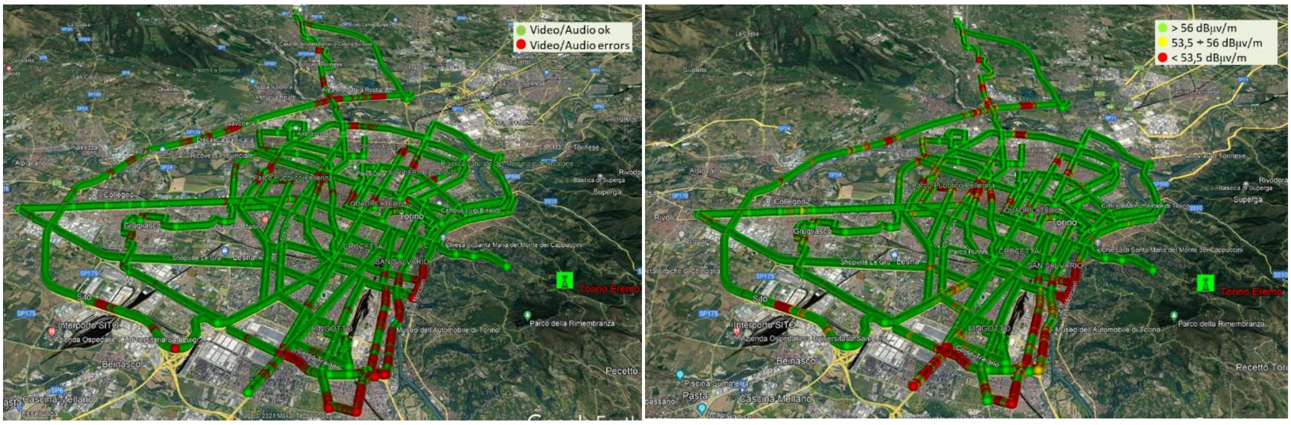


The estimated overall coverage in terms of QoE is 92.2%: this means that every 100 s, more than 92 s were correctly received while 8 s showed some video and/or audio errors. This coverage estimation also includes some areas generally considered outside the service area (e.g. the south-east area of the town, which is located at the basis of the hill hosting the HPHT and for this reason is affected by shadowing effects).

Starting from the power measurements at the input of the receiver and taking into account the antenna parameters, the EMF at approximately 2 m (height of the van) has been calculated.

FIGURE 97

Turin testbed: coverage and EMF



Looking at the maps in Fig. 97 (right side), it should be noted that the traffic lights colours system has been chosen in order to fix a kind of operating threshold in mobile reception. The idea was to find an EMF value granting over-threshold values in a percentage comparable to the measured available coverage. This operation makes sense since available coverage and EMF values are strictly correlated. Data processing established that using a threshold of 53.5 dB(µV/m) provides the 92.3% of over-threshold values, very similar to the 92.2% of measured coverage. In Fig. 97 it is evident the very close geographical correlation between the points where it was not possible to receive the signal (left side) and those where the EMF is less than 53.5 dB(µV/m) (right side).

The threshold is also useful for off-line simulations: in fact, changing the modulation scheme, the transmitting power or other parameters (i.e. the receiving antenna) it is possible to "forecast" the service coverage for a certain area.

The Turin testbed has been used on the occasion of two important demonstrations. The first one took place as part of the 5G-TOURS project [4]: Rai-CRITS experimented the delivery of high-quality linear TV services to 5G mobile phones in broadcast mode, using the most recent implementation of the 3GPP-Release 16 standard.

The second demonstration took place during the Eurovision Song Contest 2022 event, hosted in Turin from 10 to 14 May 2022. During ESC2022 Rai, simultaneously with other EBU partners in other European countries, tested the LTE-based 5G Broadcast mode adopting a LTE-based 5G Broadcast smartphone prototype provided by Qualcomm (see Fig. 98).

FIGURE 98

ESC2022 demonstration

References

[1] 3GPP TR 38.913 v14.3.0, "Study on scenarios and requirements for next generation access technologies", August 2017.

[2] 3GPP TR 36.976 v16.0.0, "Overall description of LTE-based 5G terrestrial broadcast", March 2020.

[3] Cost 207 digital land mobile radio communications final report, September 1988.

[4] https://5gtours.eu/

Annex 3

Field trials in Germany

1 5G Media2Go

1.1 Introduction

The next generation of mobile telecommunication technologies (5G) comes with a promise of various new applications. This also applies to the media and entertainment sector for the production of new forms of content and for its distribution. There seems to be an opportunity to target in particular smartphones, tablets and vehicles with both linear TV and radio programmes and nonlinear offers such as media libraries or podcasts. Future autonomous cars are considered a new very important use case for media consumption.

The broadcast, automotive and telecommunication industry have a common interest to offer users access to attractive media content and services while in a car or on public transport. The combination of linear and nonlinear content on the integrated infotainment system of contemporary cars constitutes an important step into this direction. The location or the route of the vehicle taking into consideration the expected duration of travel could be used in the future to generate recommendations thereby offering additional value for mobile media consumption.

1.2 Participants

– Südwestrundfunk (SWR, www.swr.de) – EBU member
– DFMG Deutsche Funkturm GmbH
– Dr. Ing. h.c. F. Porsche AG
– Hochschule Mainz
– Kathrein Broadcast GmbH
– Media Broadcast GmbH – BNE member
– Mercedes-Benz AG
– Rohde & Schwarz GmbH & Co. KG
– Technische Universität Braunschweig – Institut für Nachrichtentechnik
– Telekom Deutschland GmbH.

1.3 Services

– linear TV programmes
– linear radio programmes
– ARD / SWR Mediathek
– geo-referenced content recommendations (“Travelguide”).

1.4 Start date and duration

– 1 October 2020 to 30 September 2022.

1.5 Location

– Greater Area Stuttgart / Heilbronn (Germany).

1.6 Technologies

– FeMBMS (Release 14) and LTE-based 5G Terrestrial Broadcast (Release 16), LTE Unicast.

1.7 Equipment and infrastructure

– 2 HPHT transmitter sites in Stuttgart and Heilbronn
– 4 LPLT transmitter sites at mobile base station sites
– SWR signal contribution system for HPHT sites
– On-channel repeaters for LPLT sites
– LTE mobile network.

1.8 Spectrum and frequencies

– 5 MHz / 8 MHz carrier in TV channel 40 (622-630 MHz)

– Commercial LTE spectrum.

1.9 Main goals

– Verification of LTE-based 5G broadcast as a system being capable of delivering linear media services to in-car infotainment systems.

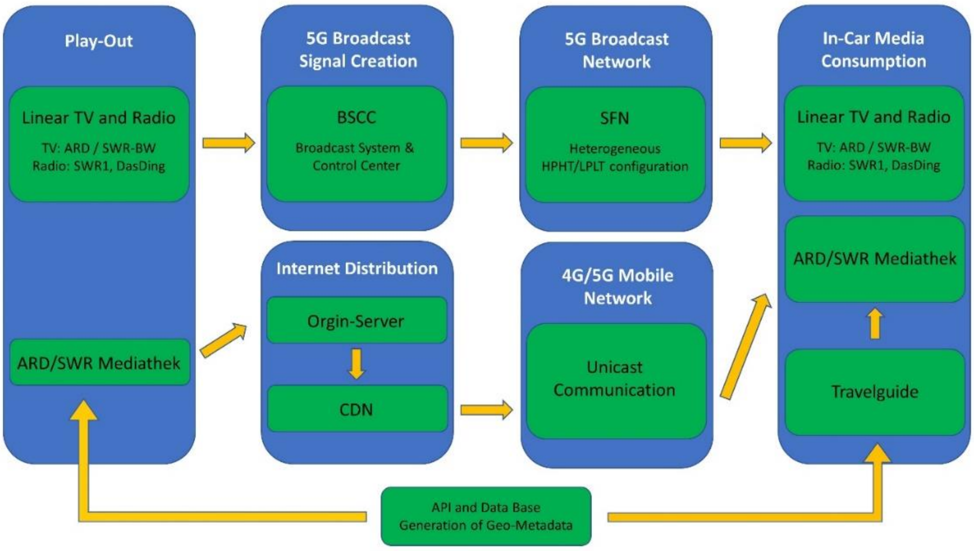
– Deployment of an LTE-based 5G broadcast network in the wider Stuttgart area consisting of two high-power-high-tower transmitters (HPHT) and a set of low-power-low-tower stations (LPLT).

– Integration of different media services in the infotainment system of a car.

– Execution of measurement campaigns to assess quality of service and coverage of the 5G broadcast transmissions.

FIGURE 99

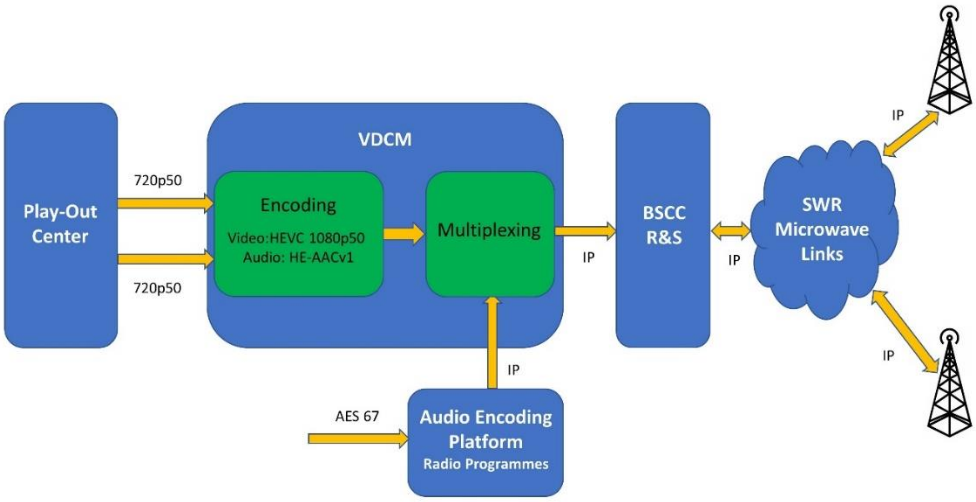
Overview of the entire distribution and usage chain



– Execution of mobile measurement campaigns in order to investigate availability of services with regards to coverage and quality of service.

FIGURE 100

Generation of LTE-based 5G broadcast signal



In order to distribute linear services by means of LTE-based 5G broadcast, a dedicated transmitter network is deployed in the 5G Media2Go project. As the project focuses on media services for infotainment systems in vehicles, the selection of the transmitter sites was guided by the intention to cover the city of Stuttgart, the highway A81 between Stuttgart and Heilbronn and highway A8 from Stuttgart westwards. Moreover, both the premises of Porsche in Weissach and the campus of Mercedes-Benz in Sindelfingen were to be covered as well.

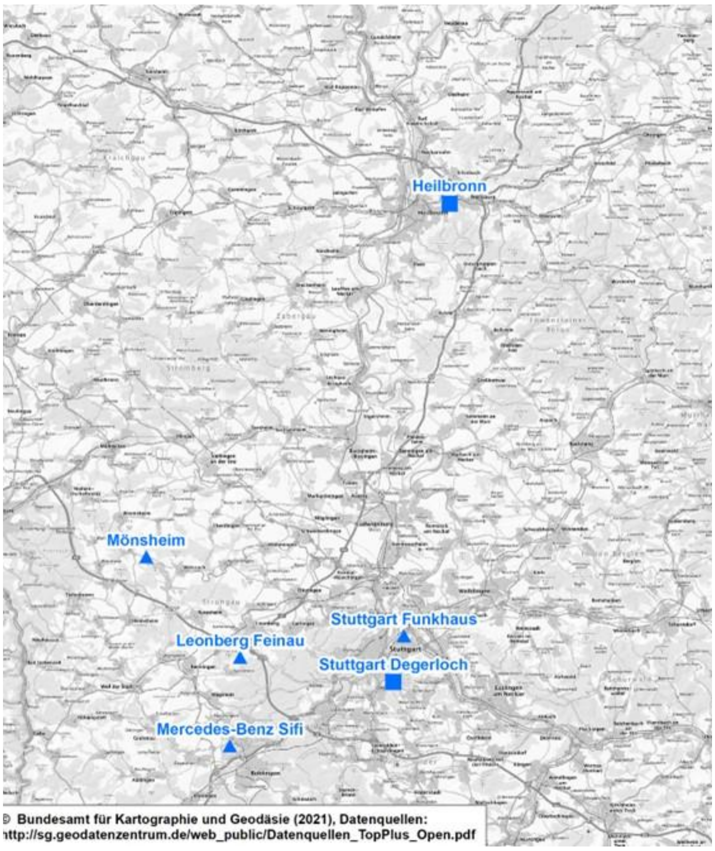
The network consists of two high-power-high-tower (HPHT) stations of SWR (Stuttgart-Degerloch and Heilbronn-Weinsberg), a small transmitter at the SWR premises in downtown Stuttgart (Stuttgart-Funkhaus), a trial station on the Mercedes-Benz campus in Sindelfingen and two mobile network sites of DFMG in Leonberg-Feinau and Mönsheim L1177. The transmitters Stuttgart-Degerloch, Heilbronn-Weinsberg, Leonberg-Feinau and Mönsheim L1177 were put into operation during the first months of the project while Stuttgart-Funkhaus was on air since December 2021. The transmitter Sindelfingen followed in April 2022.

The two main transmitters of the network in Stuttgart and Heilbronn are operating at ERPs of about 73 kW and 20 kW, respectively. The small transmitter Stuttgart-Funkhaus uses 1 kW ERP. Sindelfingen has an ERP of 743 W, while Leonberg-Feinau and Mönsheim L1177 are transmitting signals with an ERP of 288 W and 218 W, respectively. All stations are operated as a single frequency network, i.e. all stations are transmitting the same LTE-based 5G broadcast signal on the same frequency. This is an option naturally offered by all COFDM systems.

Figure 101 shows the geographical layout of transmitter network.

FIGURE 101

Geographical layout of transmitter network



1.10 Results and conclusions

The results of comprehensive measurements show that LTE-based 5G terrestrial broadcast is fundamentally suitable for the distribution of (linear) content to fast moving receivers. In 5G Media2Go particular focus lay on the examination of how the modifications introduced by 3GPP Release 16 affect the robustness of the CAS, and whether a wider subcarrier spacing used for the MBSFN subframes ensures more robust transmission at high movement speeds. In addition, the performance of the system using the wider bandwidth introduced by 3GPP Release 17 was evaluated.

The CAS investigations revealed that the 3GPP Release 16 modifications led to a robustness gain of individual physical channels of around 2 dB in comparison to what was possible in earlier 3GPP releases. A dependence of the CAS robustness on the movement speed could not be observed in the test where the highest speed driven was 180 km/h. Since the subcarrier spacing used by the CAS (15 kHz) is far wider than the Doppler shifts in that speed range, this is in line with expectations.

When examining the MBSFSN subframes, a subcarrier spacing of 1.25 kHz and 2.5 kHz was used. The subcarrier spacing of 2.5 kHz is intended to enable more robust data transmission at high movement speeds, compared to a subcarrier spacing of 1.25 kHz. However, the performance at both subcarrier spacings showed no significant dependency on movement speed. For the data encoding, mainly two different MCS values were used. MCS9 uses a QPSK with a code rate of 0.67 while MCS16 uses a 16-QAM with a code rate of 0.64. With a signal bandwidth of 5 MHz, up to 3.8 Mbit/s can be transmitted by using MCS9, while up to 7.4 Mbit/s are possible with MCS16. However, this gain in data rate comes at the price of a less robust signal, so the MCS16 needs approximately 3 dB more SNR than MCS9. Extending the channel bandwidth from 5 MHz to the newly defined option of 8 MHz, the required SNR can be reduced by up to 3 dB. This is due to two effects. Firstly, more frequency resources are available leading to a more efficient frequency-domain interleaving, which in turn increases the frequency diversity gain. Second, as the bandwidth increases, so does the individual codeword length. This enables more effective encoding by the coding algorithms, which reduces susceptibility to errors. If possible, the largest possible bandwidth should therefore be used for data transmission, as this not only enables a higher data rate, but also increases robustness.

Under the Travelguide service thread of 5G Media2Go a system was developed which offers geo-referenced recommendations for content in the ARD/SWR Mediathek. To this end, a corresponding interface was developed.

In order to geo-reference Mediathek content, the available videos were processed in different ways both manually and automated based on analysing audio track, video description, metadata and image data. By combining the transcribed audio track and the metadata associated with a video such as title, synopsis, keywords, a prototype process was implemented that automatically geo-references the content.

A location score that maps the quality of the location reference of a specific video was prototypically designed. Using the Travelguide service developed, content from the media library can be searched, filtered and retrieved depending on location data. In addition, a Web app was developed that uses this API and provides further functionalities.

In total, more than 52 000 videos could be geo-referenced. Due to playout rights constraints, only around 28 000 videos are currently available in the database. The core of the project was the realization of a Web API, through which the service is made available to the automotive partner and can thus form the foundation for applications based on it. Using the Porsche infotainment system as an example, video content can be queried around the current location of the vehicle or along a possible travel route. It can then be displayed in the integrated player on the passenger panel.

In summary, the following major conclusions can be drawn from the investigations carried out in 5G Media2Go:

– LTE-based 5G broadcast is capable to deliver linear TV and radio services to smartphones and infotainment systems in vehicles.
– LTE-based 5G broadcast supports delivering linear services at high speeds of up to 180 km/h.
– LTE-based 5G broadcast can be configured to distribute different data stream formats, e.g. MPEG Transport Stream and MPEG DASH.
– LTE-based 5G broadcast supports network operation in single frequency mode including both HPHT and LPLT transmitters.
– The integration of LTE-based 5G broadcast transmissions alongside with unicast communication on infotainment systems of vehicles to grant access to non-linear services is straightforward. This allows to offer hybrid services which combine linear and non-linear elements.
– A particular spin-off of the project is the Travelguide application. The relevance of geo-referenced recommendations will increase as mobile media consumption will grow.

Further technical details can be found in the GMedia2Go Report[2].

2 LTE-based 5G broadcast in Hamburg

2.1 Summary

The pilot project comprises of two SFN transmitters (43 dBW and 37 dBW ERP, respectively) and a repeater to cover the main trains station (up to 7 dBW ERP), as well as a corresponding playout

2 https://drive.google.com/file/d/1CznXRhhNboNVvXVI6oTqiF2f6brlONxb/view

centre. The impact of the parameters (like MCS) on the reception were/will be measured in order to get a better basis for network planning. Warning functionalities will also be tested. It is not a funding project. Thus, it is open for any other testing and development in the context of video distribution for broadcasters.

2.2 Participants

– Norddeutscher Rundfunk (NDR) (www.ndr.de) – EBU member

– Media Broadcast (MB) BNE member.

2.3 Services

– Up to three Video services (partly live), sometimes also audio services

– *(open for changes and extensions)*.

2.4 Start date and duration

– Show case started in October 2021

– Pilot project planned at least until mid-2026.

2.5 Location

– Hamburg (Germany).

2.6 Technologies

– LTE-based 5G broadcast.

2.7 Equipment and infrastructure

– Virtual Digital Content Manager – VDCM (Synamedia)

– Broadcast Service and Control Centre – BSCC (R&S) and MediaCast Mobile (Enensys)

– Transmitters (R&S).

2.8 Spectrum and frequencies

– 5 MHz at channel 40 (extension to 8 MHz is prepared).

2.9 Main goals

– The main goal is to clarify open questions for preparing decisions with respect to an introduction of LTE-based 5G broadcast, e.g. analysis of reception conditions depending on different parameters, further measurements, interoperability tests, foundations for frequency and network planning, experiences with receiving devices and development/test of possible applications (open for any other question that will come up during the project).

– Emergency warnings using cell broadcast are studied regarding robustness using different MCSs as well as different kinds of emergency related media in various languages. It is planned to investigate dynamic MCS changes and an automatic activation of specific video information in case of warning needs. The coverage with robust variants (MCS 2 to 5) should be determined – both indoor and outdoor. Furthermore, thoughts about networks with repeaters and frequency conversion will be made.

2.10 Highlights

– Project is running since 2021. Currently, there is often only one transmitter in operation, due to self-interferences (pre-Release 14).

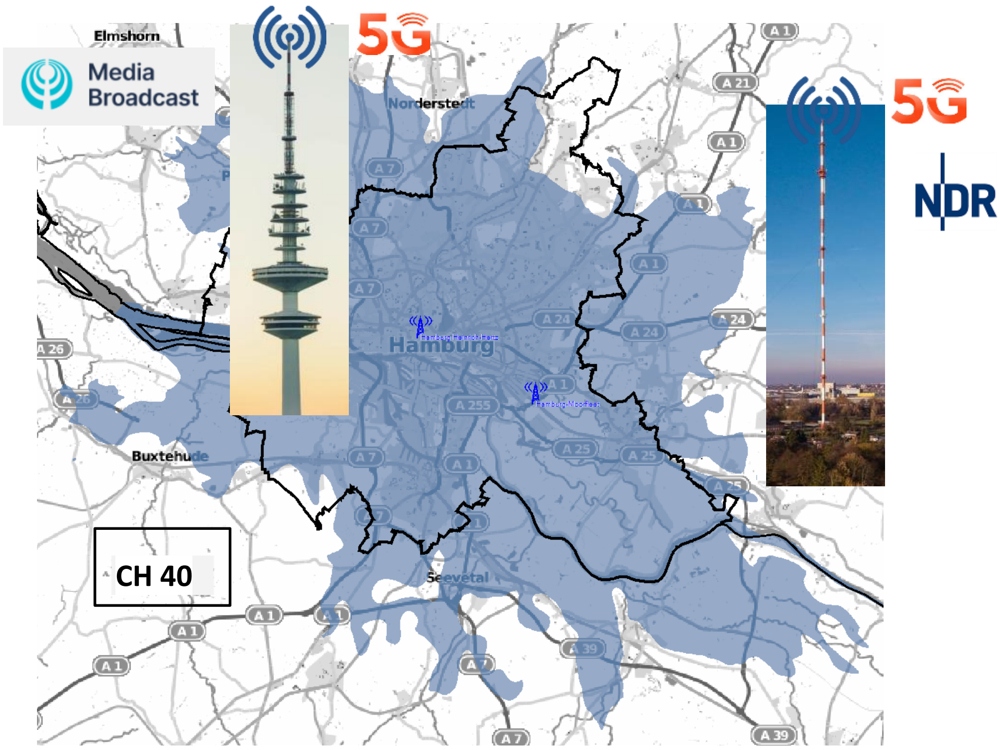
– Tests were carried out with different core components.

– A repeater has been installed in the main train station, which improves coverage within halls, shops and across platforms.

– The network is prepared for an operation of 8 MHz wide signals but is still operated with a 5 MHz wide signal, due to the still existing limits of the test devices. The channel was changed from CH34 to CH40 in order to make tests and demonstrations with mobile devices (pre-Release 14, modified) from OnePlus, Xiaomi and Motorola.

FIGURE 102

Intended service area of trial



3 LTE-based 5G broadcast in Halle

3.1 Summary

The pilot project consists of a single transmitter (1 kW ERP) and a corresponding playout centre. The impact of different parameters on the reception will be measured and different configurations will be tested in the playout, with respect to bitrates and video quality.

3.2 Participants

– Media Authority in Sachsen-Anhalt (MSA)

– Media Broadcast (MB) – BNE member

3.3 Services

– Several video signals (TV) incl. audio services, depending on the test scenario and playout configuration**.**

– *(open for changes and extension).*

3.4 Start date and duration

– Show case started in June 2024.

– Pilot project planned at least until May 2026.

3.5 Location

– Halle (Germany).

3.6 Technologies

– LTE-based 5G broadcast.

3.7 Equipment and infrastructure

– Broadcast Service and Control Centre – BSCC (R&S)

– Transmitters (R&S).

3.8 Spectrum and frequencies

– 5 MHz at channel 40 (to be extended to 8 MHz).

3.9 Main goals

– The main goal is to clarify open questions for preparing decisions with respect to an introduction of LTE-based 5G broadcast. This includes an analysis of reception conditions depending on different parameters, additional measurements to support network planning, experiences with receiving devices, development of possible applications and test of different playout configurations (e.g. new codecs, passthrough into BSCC, variation of bitrates).

3.10 Highlights

– Project started in June 2024.

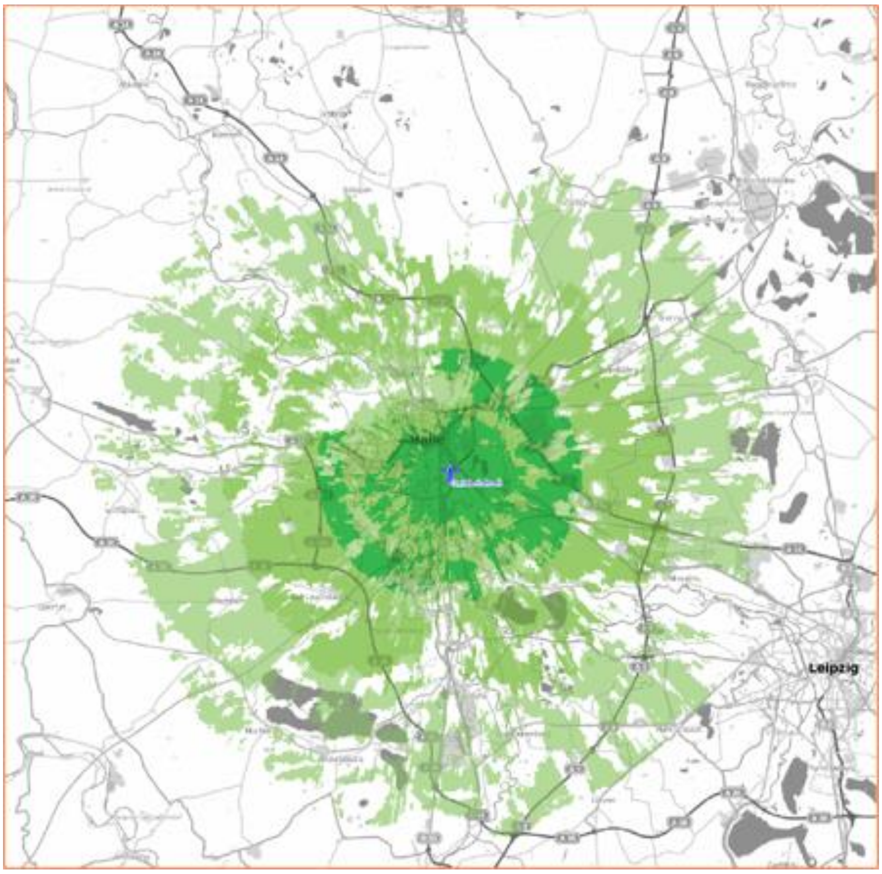
– Different mobile devices (all pre-Release 14, modified) were used for tests and demonstrations. This includes the development of an App, which was successfully tested and is used on all these phones.

– The network is prepared for an operation of 8 MHz wide signal but still in operation with 5 MHz (mobile devices with pre-Release 14).

– Different signal configurations are to be tested to verify lab results, e.g. concerning statistical multiplexing (transparent multicast passthrough into BSCC) and HEVC.

FIGURE 103

Service area of trial of "LTE-based 5G broadcast in Halle"



MCS-21 (16 MBit/s)
MCS-18 (12 MBit/s)
MCS-11 (7 MBit/s)

Annex 4

Vienna (Austria) field trials

1 Summary

Assessing the performance of FeMBMS (Release 14) and LTE-based 5G broadcast (Release 16) in comparison with DVB-T2 and DAB+. Studying product maturity of infrastructure and receivers with close cooperation to manufacturers. Evaluating hybrid use cases and applications (e.g. combining LTE-based 5G broadcast with broadband networks to provide a seamless switch experience to the user) and evolving the 5G broadcast ecosystem.

2 Participants

– Austrian Broadcasting Corporation (ORF) – Public Broadcaster, Content Provider TV and Radio (http://orf.at – EBU member)

– Austrian Broadcasting Services (ORS) – Broadcast Network Operator (http://ors.at) – BNE member)

– Servus TV – Private Broadcaster, Content Provider TV

– ProSiebenSat.1 PULS 4– Private Broadcaster, Content Provider TV for Puls24

– KroneHit – Private Broadcaster, Content Provider Radio

– Vienna University of Technology Institute for Telecommunications – Link Level Simulations.

3 Services

– Linear TV and Radio (RTP, HLS, DASH in various configurations[3])

– Emergency Warning Tests.

4 Start date and duration

– Phase 1: 2020-2021 – Comparison DVB-T2 vs LTE-based 5G broadcast

– Phase 2: 2021-2023 – Investigation of hybrid applications and further development of the 5G broadcast ecosystem.

5 Location

– Vienna (Austria)

6 Technologies

– FeMBMS (Release 14) and LTE-based 5G Terrestrial Broadcast (Release 16)

7 Equipment and infrastructure

– Commercial equipment and Infrastructure:
  - 2 HPHT Transmitter Sites
  - 2 Core Systems

– Open-source receiver (OBECA/5G-MAG Reference Tools)

– Open-source transmitter (5G-MAG Reference Tools)

– Smartphone-formfactor devices with LTE-based 5G broadcast receiving capability.

8 Spectrum and frequencies

– 739 MHz, max bandwidth 10 MHz before 1.7.2020

– 667 MHz, max bandwidths [8 MHz (Kahlenberg transmitter), 10 MHz (Liesing transmitter)] from 1.7.2020

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[3] Use-Case defined settings for Modulation Coding Scheme, Bandwidth and Services.

– 640.5 MHz, max bandwidth 5 MHz (Liesing transmitter) from 1.2.2022.

9 Main goals

- Open testbed for Broadcast Network Operators, Mobile Network Operators, Set Top Box and chip manufacturers
- Study product maturity of infrastructure and receivers with close cooperation of manufacturers
- Support the evolution of a LTE-based 5G broadcast ecosystem by developing and providing an open-source receiver for own and other trials and application developer
- Phase 1:
  - Compare simulation and measurements of FeMBMS Rel.14 (and Rel.16) with DVB-T2 and DAB+
  - Technical evaluation of LTE-based 5G broadcast use-cases and applications.
- Phase 2:
  - Hybrid use-cases LTE-based 5G broadcast and Broadband
  - Further development of the LTE-based 5G broadcast ecosystem.

10 Highlights

- Results from phase 1 of the trial have been summarized in a CEPT input paper[4]

  Development of the world's smallest open-source LTE-based 5G broadcast receiver "OBECA" 2021
- First reception tests and measurements within a high-power-high-tower testbed with a smartphone-formfactor device with LTE-based 5G broadcast reception capabilities in February/March 2022
- Nakolos: a solution for Broadcaster, Content Provider and Broadcast Network Operators to offload traffic from Content Delivery Networks (CDNs) utilizing LTE-based 5G broadcast. It helps Broadcasters and Content Providers to keep their CDN distribution costs under control[5]
- Resilient PNT based on LTE-based 5G broadcast (testbed for a joint project of the European Space Agency and Rohde & Schwarz)[6]
- First tests with a commercial research device, i.e. a commercially available phone which was re-configured as a research device for LTE-based 5G broadcast reception in January 2023.

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[4] https://www.ors.at/fileadmin/user_upload/ors/5G_Broadcast/PTD_21_012_Technical_implementation_status_of_5G_Broadcast_-_Vienna_Field_Trial_.pdf

[5] https://nakolos.com

[6] Field test support for a project by ESA and Rohde & Schwarz: https://navisp.esa.int/project/details/167/show

FIGURE 104

Vienna testbed overview with the two transmitters (Wien Kahlenberg, Wien DC Tower and Wien Liesing), the LTE-based 5G broadcast core location at the public broadcaster

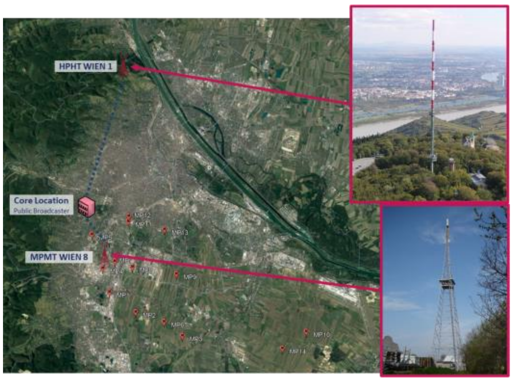


FIGURE 105

Mimicking mobile users with the self-developed measurement setup using a bicycle trailer in 2020 (~80 kg, containing battery packs, 2 measurement systems and laptops for up to 3 hours measurements)

FIGURE 106

LTE-based 5G broadcast reception platform OBECA, by February 2021 the world's smallest open-source receiver for LTE-based 5G broadcast. Now part of the 5G-MAG Reference Tools

Annex 5

LTE-based 5G terrestrial broadcast trials in Italy

1 LTE-based 5G terrestrial broadcast trial in Italy/Aosta Valley

1.1 Summary

The main scope of this trial is:

– Provide LTE-based 5G broadcast delivery to massive audiences with HPHT infrastructure;

– Study the performance of an LTE-based 5G broadcast signal in mobility (in-car scenario) and urban outdoor (coverage analysis);

– Improve video user's experience;

– Distribute of audio-visual (A/V) content and services to a potentially unlimited number of users.

1.1.1 Participants

– RAI (Public Service Media Organization – TV Content Provider – Broadcast Network Operator) (www.rai.it) – EBU member

– Rai Way.

1.1.2 Services

– Provide high-quality video media content and service to mobile devices using conventional terrestrial broadcast network infrastructure.

1.1.3 Start date and duration

– November 2021 to June 2022.

1.1.4 Location

– Aosta Valley (Italy).

1.1.5 Technologies

– LTE-based 5G Terrestrial Broadcast (Release 16).

1.1.6 Equipment and infrastructure

– Two HPHT transmitter sites in SFN (Single Frequency Network) mode

– EnTV/EPC core by Rohde & Schwarz

– hardware/software defined receiver (SDR) by Rohde & Schwarz and iFN

– hardware/software defined receiver (SDR) by OBECA.

1.1.7 Spectrum and frequencies

– UHF channel 53 (730 MHz centre frequency).

1.1.8 Main goals

– Implement a standalone-dedicated broadcast mode deployed on terrestrial broadcast network infrastructure

– Setup and experimentation of a single frequency network (SFN)

– Distribution of live TV broadcast over a dedicated broadcast network to mobile devices
– Mobile reception (in vehicles)
– Free to air reception.

1.2 Field tests

Road measurements with an omnidirectional antenna mounted on the top of the van in Aosta Valley have been carried out to collect data about the achievable coverage and the required network configurations to ensure the service, to record the RF signal in different conditions for off-line evaluations on the mobile reception availability, to evaluate the EMF availability and to identify an operating "threshold" for the mobile reception.

To obtain these results, a van was equipped with the following instruments:

– LTE-based 5G Broadcast receiver: Rohde & Schwarz SDR receiver;
– RF recorder: Lumantek Weiver 2.0;
– receiving antenna positioned on the top of the van;
– GPS antennas for georeferencing of measurements;
– monitors positioned in the headrests for observation of the received video;
– notebook with software designed by Rai CRITS for error detection and data logging of the EMF, van speed and geographical position.

The modulation parameters used during these measurement campaigns are based on the results of the preliminary laboratory tests and are a trade-off between the required robustness in a mobile reception context and the available capacity. Table 35 shows the transmission parameters adopted and the frequencies used in the testbed.

TABLE 35

Transmission parameters – Aosta Valley test bed

Modulation scheme	MCS12 (16-QAM, rate 0.42)
Subcarrier spacing (SCS)	1.25 kHz (cyclic prefix = 100 μs)
Bandwidth	5 MHz
CAS	Release 16
Available bit rate	4.83 Mbits/s
Frequency	UHF ch. 53 (CF = 730 MHz)

1.2.1 The Aosta Valley testbed

The Aosta Valley region has very often been the scenario for RAI Research Centre experiments, especially since the advent of digital technologies in the 90s. The reason for using the Valley lies in its peculiar topography which is particularly complex from a signal propagation and reception point of view. The numerous side valleys and the large number of required transmitter sites to cover the area, also make the Aosta Valley perfect for testing SFN. Furthermore, the possibility of travelling along a dense secondary road network, close to the main valley which often climbs up steep mountain slopes frequently hidden from the transmitters, provides a demanding test case for the reception of mobile TV.

Furthermore, transmitting the LTE-based 5G Broadcast signal from two different HPHT sites, with partially overlapping coverage areas in the region of Aosta town, has made it possible to experiment with a SFN in a realistic operational environment. For these reasons, the Aosta Valley testbed has been an excellent test bench for LTE-based 5G Broadcast technology.

Rai CRITS activated the testbed in the Aosta Valley in November 2021, transmitting signals on UHF channel 53 (730 MHz) in horizontal polarization. The set-up included the activation of two transmitters (see parameters in Table 36):

– Transmitter 1: Aosta – Gerdaz, located in the south of Aosta, on the mountains surrounding the town, at about 5 km in line of sight from the city centre.

– Transmitter 2: Saint Vincent – Salirod, located close to the town of Saint Vincent, at about 4 km in line of sight from the city centre.

TABLE 36

Aosta Valley sites parameters

Transmitter	Coordinates	Height	Frequency (CF)	Pout
Aosta-Gerdaz	45°42’08’’ N – 7°18’35’’ E	1 366 m (asl (1)) – 770 m (agl (2))	730 MHz (ch. 53)	50 W
Saint-Vincent-Salirod	45°44’38’’ N – 7°40’41’’ E	1 114 m (asl (1)) – 550 m (agl (3))	730 MHz (ch. 53)	100 W

(1) Above sea level.

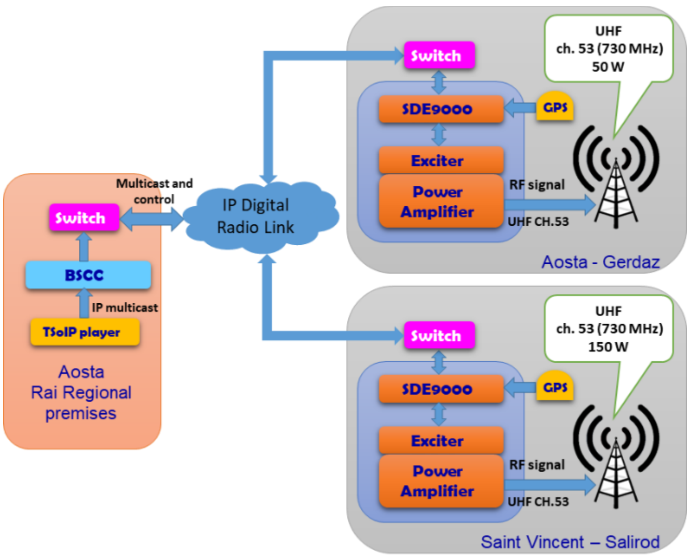
(2) Above ground level (Aosta city).

(3) Above ground level (Saint-Vincent city).

A pre-recorded TsoIP at a desired bit rate has been played in the Rai Regional premises of Aosta where it was located the BSCC, connected to the two transmitter sites by means of an IP digital radio link. The set-up of the testbed is reported in Fig. 107.

FIGURE 107

Aosta Valley testbed set-up

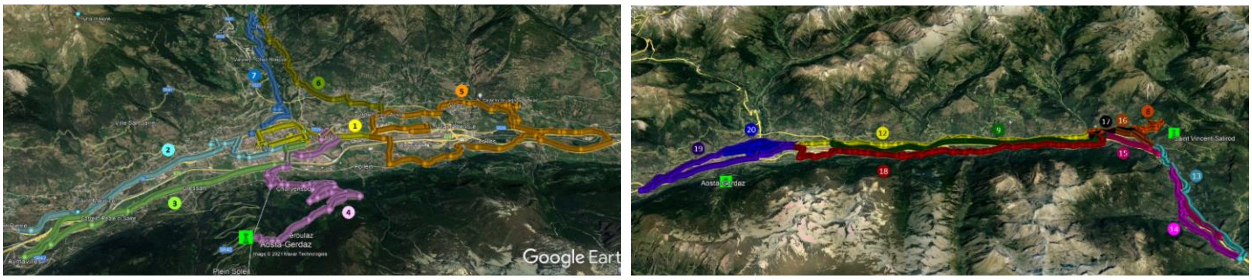


After checking the radiant systems, the coverage of each single transmitter has been analysed, in order to have an exhaustive picture of the overlapping areas. These data are of fundamental importance to set up the SFN properly and to carry out coverage measurements in the most significant areas. As done in the Turin testbed, the measurements have been carried out on routes in the main towns in the

SFN service area, the highway running through the main valley and the suburban areas that often lie in the lateral and narrower valleys. Thus, 18 routes have been identified for a total of more than 250 km travelled, as illustrated in Fig. 108.

FIGURE 108

The Aosta Valley routes, (a) Aosta – Gerdaz, (b) Saint Vincent – Salirod



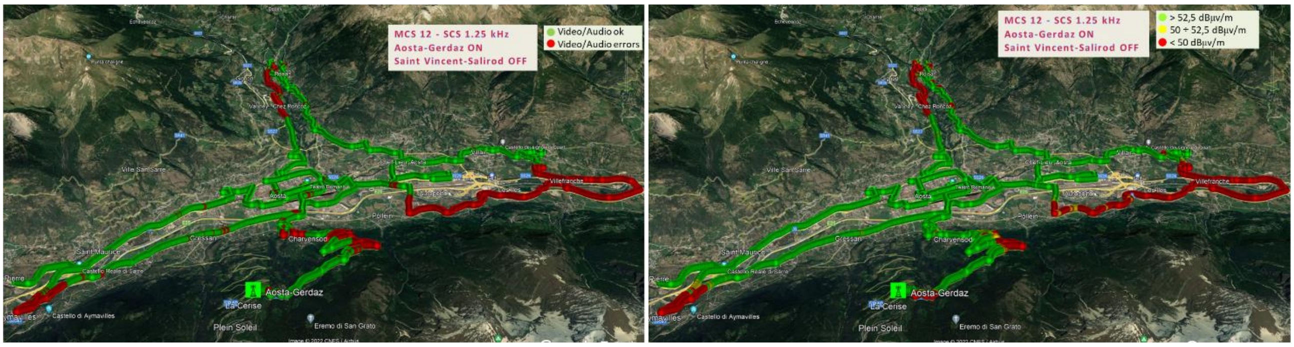
(a) (b)

For each route, coverage has been evaluated by monitoring the audio/video and reporting the points where errors were detected; then, such errors have been acquired and georeferenced by using a special software developed in our laboratories. In addition, the power values at the receiver input and the RF signal were recorded for subsequent off-line analysis. From the power values and on the basis of the characteristics of the receiving antenna (i.e. antenna factor) the EMF at a height of 2 metres has been extrapolated.

The processing of the acquired data allowed us to obtain the coverage maps for each single transmitter and an EMF value threshold. As an example, the coverage relating to the Aosta – Gerdaz transmitter and the EMF map are shown in Fig. 109.

FIGURE 109

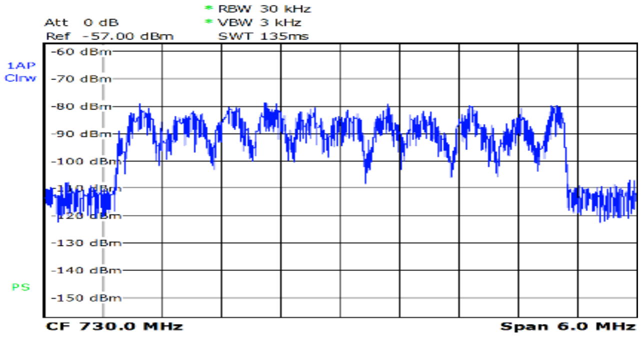
Aosta – Gerdaz coverage and EMF



Considering a threshold of 50 dB(µs V/m), the number of measured seconds during which the EMF has been over-threshold is quite similar to the coverage percentage; as in the case of the Turin testbed, there is a very close geographical correlation between the points where it is not possible to receive the signal and those where the EMF is under threshold, as it is clearly visible in Fig. 110. The difference between the threshold value identified in the Turin testbed (53.5 dB(µs V/m)) and the one obtained in the Aosta Valley is due to a different sensitivity of the receiver in VHF band compared to the UHF band performance used instead in the Aosta Valley. Another reason that justifies this difference is that in the Aosta Valley, differently from the Turin testbed, the urban area is quite limited compared to the suburban area where the mobile reception is simpler because very often the transmitter site is in line of sight with the receiving antenna.

FIGURE 110

Spectrum at Aosta airport

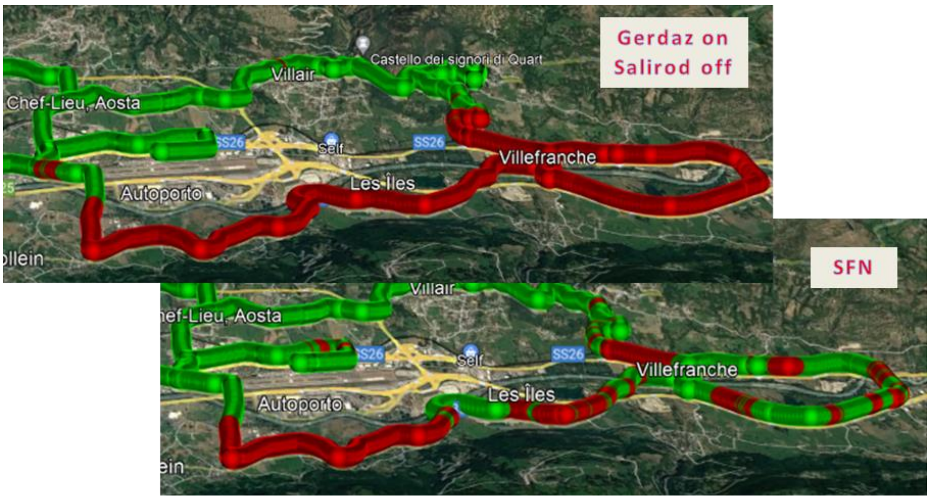


The following step has been to set up and verify the correct behaviour of the SFN network. Therefore, after verifying all the network parameters set by means of the BSCC, some test points were identified in the overlapping area of the two transmitters, where measurements were carried out using a vehicle equipped with a 10 m telescopic pole. For each of these measurement points, a static delay has been set on the Aosta – Gerdaz transmitter to get a relative delay between the two transmitters equal to 1 µs. This way, using a spectrum analyser and rotating the antenna so that the received power from the two transmitters were as similar as possible (i.e. C1/C2 = 0 dB), it was easy to observe "holes" (typical in an SFN context) within the spectrum at a distance of about 1 MHz (1/1 µs). As an example, Fig. 110 shows the measurement point of Aosta – Saint Christophe. Similar results were obtained in other three selected points. These preliminary measures allowed us to verify the synchronization of the SFN.

Once the correct functioning of the SFN had been verified, hence keeping both transmitters switched on, coverage has been measured again in the service area: we have focused on the overlapping area of the two transmitting systems, namely the urban area of Aosta and the west suburban area of the city. Basically, the paths shown in Fig. 108 (a) were retraced, in order to further validate the SFN and to appreciate the improvements in coverage thanks to the combined effect of the two transmitters. For example, route 5 (see Fig. 111), one of the most subject to the combined effect of the two transmitters, sees an increase in coverage from 58% to over 68% when operating in SFN mode. The relatively low value of the coverage is due to the fact that the route includes some areas, especially in the south of Aosta, where both transmitters are shielded from the surrounding mountains.

FIGURE 111

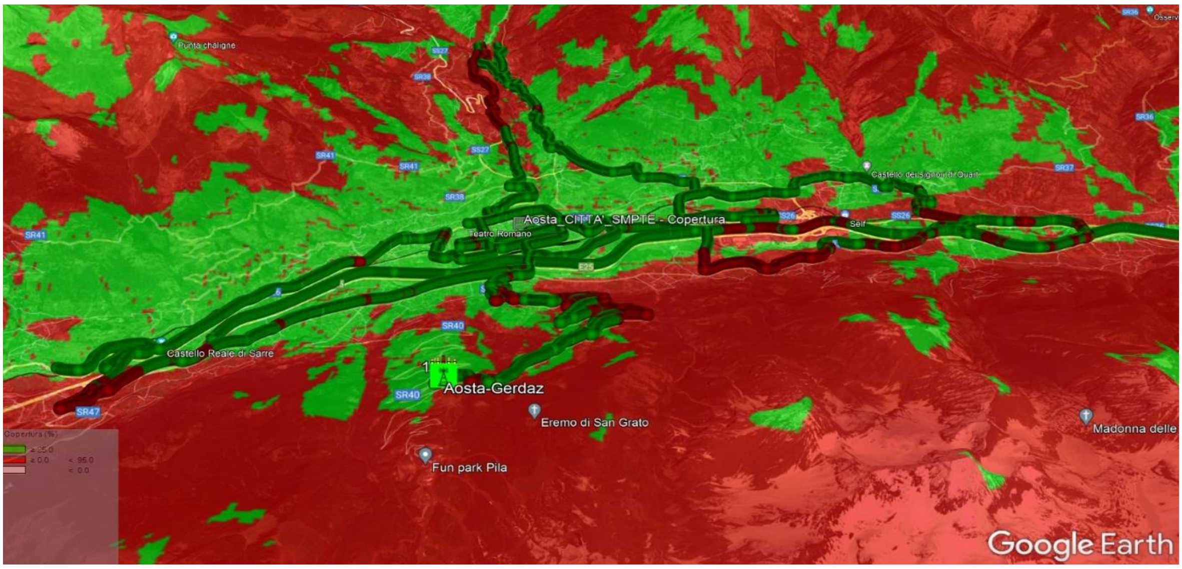
SFN coverage increasing in Aosta



As a further element of comparison, an attempt was made to compare the predicted values of the simulative analysis considering a single threshold value placed at 95% of the covered locations, with the field measurements, finding a very good agreement as can be easily verified in Fig. 112. Of course, such an approach needs to be further investigated: if confirmed, it would indicate that mobile reception is reliable in areas where the simulations provide a coverage rate of over 95%.

FIGURE 112

Simulations vs measurements



2 5G audiovisual broadcast broadband network in Turin and Palermo (Rai Way – Italy)

2.1 Summary

On July 2022 Rai Way was awarded the "5G Audiovisual 2022" tender of the Ministero delle Imprese e del Made in Italy, former Ministero dello Sviluppo Economico, obtaining also 1 million Euro funding.

The one-year project had the main objective of experimenting with innovative technologies based on 5G networks in the sector of the production, distribution and broadcasting of innovative live audiovisual content.

2.2 Participants

– Rai Way S.p.A.
– Rai Radiotelevisione Italiana
– Municipality of Turin
– Rohde & Schwarz
– Politecnico di Milano
– OpNet
– MainStreaming
– Impersive
– Kinecar
– RETESETTE

– La Sicilia Multimedia
– Teatro Massimo (Palermo).

2.3 Start Date and Duration

– July 2022 to July 2023

2.4 Location

– Turin and Palermo

2.5 Technologies

– 3GPP Release 16 feature set and seamless switching broadband/broadcast

2.6 Equipment and Infrastructure

– Fiber Optic and Radio-Link network Rai Way and OpNet
– Two Rai Way HPHT sites, one in Turin and one in Palermo, based on Rohde & Schwarz LTE-based 5G broadcast technology
– CDN Broadband in Turin and Palermo and CDN local Edge (Dedicated Broadband MainStreaming in Turin)
– Prototype LTE-based 5G broadcast-compatible handsets
– SDR receiver with capabilities of seamless switching broadband/broadcast, developed by Politecnico di Milano on the basis of 5G MAG Reference Tools, also integrated on the infotainment system of a minicar, to allow for car mounted vehicular reception.

2.7 Spectrum and frequencies

– 5 MHz, 743-748 MHz band – SDL-B2.

2.8 Main goals

The main goal was experimenting with innovative technologies based on 5G networks in the sector of the production, distribution and broadcasting of audiovisual content.

2.9 Highlight

In the field of audiovisual production, innovative use cases were created through the use of 5G private networks like, e.g. a multistage live jazz concert with synchronous contribution from the musicians present in different locations and immersive live VR 360 shooting of cultural events.

FIGURE 113

5G private network test in Nokia laboratory

The trial provided a comprehensive overview of the extensive potentialities of the cutting-edge combination of LTE-based 5G broadcast and CDN technologies for the linear broadcast and broadband distribution.

Rai Way and the aggregation of partners created synergies between innovative audiovisual production, contribution and distribution networks, implementing an immersive and engaging live artistic content, even in teaching scenarios and demonstrating with the experimentation project the potential of the HPHT Rai Way broadcast network.

The use cases refer to specific “Live Events”: TV contents, including live streams captured by means of a 5G remote production and VR360 content for full immersive experiences, have been distributed via LTE-based 5G broadcast to handheld devices, VR headsets and vehicular infotainment systems, implementing seamless switching between broadcast and broadband delivery to offer an uninterrupted viewer experience.

In the field of content production, the project exploited 5G Private Network technology to support distributed and remote television production of live events. The main objective was to reduce latency of a 5G Private Network and audio/video digital encoding systems (some tens of ms), so that a jazz band, with some components in distant places, could play together a jam session. At the same time, the network had to guarantee signals of adequate quality to the remote control room for live broadcasting on television channels.

In fact, in the context of Torino Jazz Festival 2023, a jazz improvisation of a 16-professional big band was shown, whose musicians, in addition to playing on stage, took turns in the different remote areas. With the contents of the same live performance different experiences were put in place: on smartphones and tablets, in the metaverse with headsets and live for an audience enjoying the show.

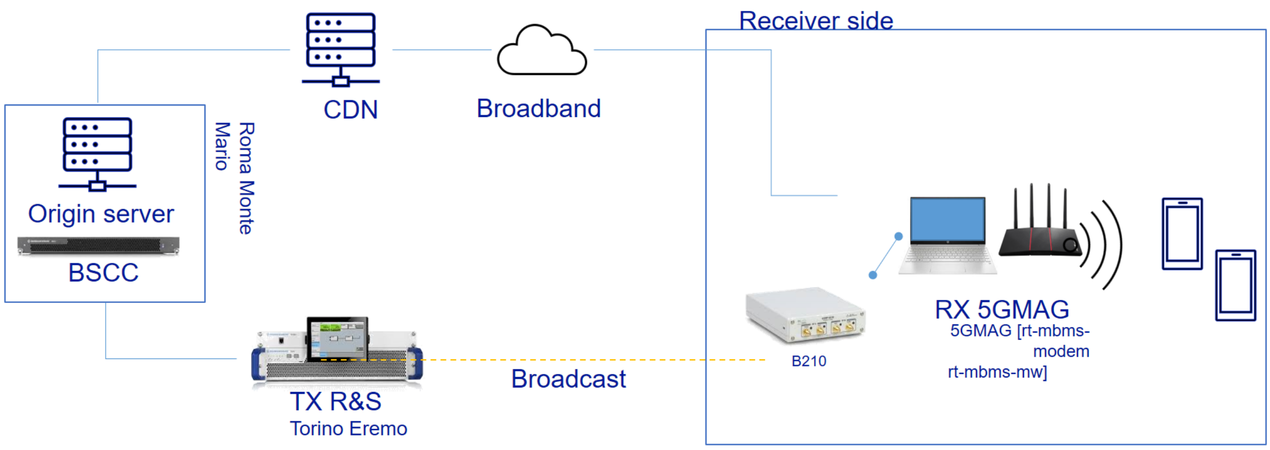
In the field of content distribution, in Massimo Theatre of Palermo, VR360 live signals were produced. The LTE-based 5G broadcast VR360° signal was received by a fixed rooftop antenna and the SDR prototype receiver, to be finally retransmitted via Wi-Fi6 to VR headsets with a high QoE. The reception place was both in a conference room inside Massimo Theatre where invited participants were present and at a Palermo school called “Convitto Nazionale Falcone” where many students were present with their teachers. A similar use-case has been realized at the Modern Art Gallery in Turin.

For the automotive use case, the prototype receiver has been integrated in the infotainment system of Kinecar, a highly connected minicar, to allow car mounted vehicular reception, with a good QoE along the streets of Turin: the multimedia live contents of the Italian broadcasters Rai, Antenna Sicilia and RETESETTE were used to feed the LTE-based 5G broadcast and broadband networks, to reach the vehicle infotainment system and via Wi-Fi mobile commercial devices (smartphones and tablets) used by the passenger.

The coverage, guaranteed by HPHT sites, was combined in deep urban areas with the usage of 5G data connectivity (OTT, unicast): the seamless switching between broadcast and broadband delivery allowed the uninterrupted service consumption for a satisfactory Quality of Experience.

FIGURE 114

Receiver-side integration and seamless switching



The integration between broadband and broadcast services was achieved by means of an additional application level, named Seamless Switching Application (SSA) running on the receiver and developed by Politecnico di Milano.

The trial was a combination of LTE-based 5G broadcast and CDN technologies and the high-level architecture of the application consisted of a HTTP server that responded to video streaming requests through three channels: the broadband (BB), the broadcast (BC), and the switching channel (BS).

The BC source was developed by Politecnico di Milano on the basis of the demodulator (version 1.2.2) and MBMS client (version 0.9.2) of the 5G-MAG Reference Tools.

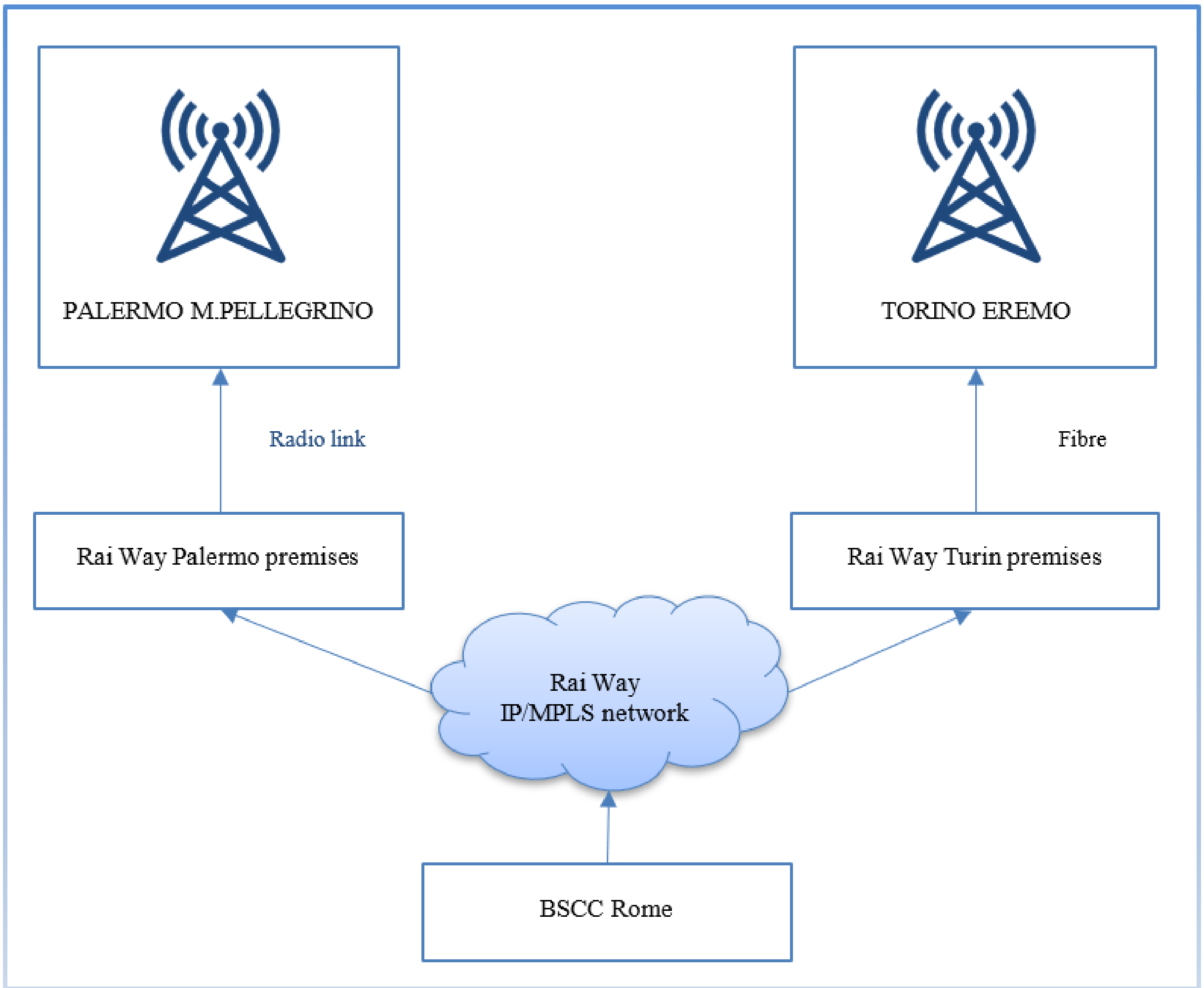
The BS channel was managed by the application and enabled the manual or automatic switching between BB and BC according to specific commands or receiver conditions.

2.10 Technical details of the 5G network and results of the trials

For this project a network with two 5G transmitters which served Palermo and Turin was set up and it was optimized for an outdoor mobile reception scenario. The content has been prepared by an ad-hoc equipment located in Rome and then deployed through the IP/MPLS network of Rai Way to the regional Rai Way premises and then through fibre or radio link to the transmitting sites.

FIGURE 115

Rai Way transmission and broadcasting network connections scheme



TORINO EREMO and PALERMO M.PELLEGRINO are two Rai Way HTHP sites and two new 5G transmitters have been installed and combined with the existing infrastructure.

The system characteristics are reported in Table 37.

TABLE 37

System characteristics

Modulation and coding schemes	MCS 12 – 16-QAM, code rate 0.42
Sub carrier spacing	1.25 kHz (cyclic prefix = 200 µs)
Bit rate	4.816 Mbit/s
CAS	Release 16
Frequency	SDL-B2 at 746 MHz (channel 55)
Channel bandwidth	5 MHz
Output power	500 W (Pol H)
Maximum ERP value	TORINO EREMO: 12 dBk PALERMO M.PELLEGRINO: 8 dBk

The calculation of the coverage areas of the two HTHP sites has been done by using the Recommendation ITU-R P.1812 propagation model, on a DTM at 10 m resolution and by considering a clutter layer having the same resolution. The planning simulation of the service area has been carried out considering the output power and antenna diagram of the transmitters, the antenna gain of the receiver, −3 dBi, and the *C*/*N* value corresponding to the 5G broadcast reception scenario, 18 dB (this value has been set after laboratory tests). In the maps presented in the following sections, the zones where the reception location probability, LP, is ≥ 95% (good quality) are coloured in red (Palermo) or in light blue (Turin) and in blue where the LP is ≥ 70% (acceptable quality). Where the theoretical service is provided with LP < 70% (low or unacceptable quality), there is no colour.

Some measurements campaigns have been carried out in order to verify the correspondence of the planning with the real service availability, to assess the quality of service under different conditions and to identify a possible operational threshold for the mobile reception.

The tests, performed in the metropolitan area of Turin and Palermo, permitted to evaluate the performance of the 5G service in a densely populated area, with tall buildings and obstacles that often prevent the line-of-sight reception. Tests done on the motorway allowed to assess the performance in medium/high-speed conditions (typically ≤ 80 km/h).

For these campaigns RAI CRITS (Centro Ricerche, Innovazione Tecnologica e Sperimentazione) prepared an equipped vehicle and developed a specific software that permits to detect the reception errors without the intervention of an operator, thus making the data acquisition more accurate and straightforward. This application, based on the received bit rate and on the CRC errors, determines three possible reception conditions:

– QEF reception, in green on the maps: reception with no audible and visible errors, that corresponds to a received bit rate greater than 95% of the expected value and no more than two CRC errors in a second.
– ‘Threshold’ reception, in yellow on the maps: reception with few video blockings and artefacts but still acceptable, that corresponds to a received bit rate greater than 95% of the expected value and three CRC errors in a second.
– Reception with errors, in red on the maps: reception with continuous video and audio blockings, that corresponds to a received bit rate less than 95% of the expected value or four or more CRC errors in a second.

In the field tests, the coverage is estimated in terms of error-free seconds: as an example, a percentage of 93 means that for every 100 seconds, approximately 93 seconds are received correctly, while 7 seconds show some video and/or audio errors.

2.10.1 Palermo field test

In Palermo, in order to investigate the availability and the quality of the service, 23 different itineraries for a total amount of around 200 km have been identified and in Fig. 116, these paths with the related speed are displayed. To be noted that not all of them are inside the service area of the transmitter.

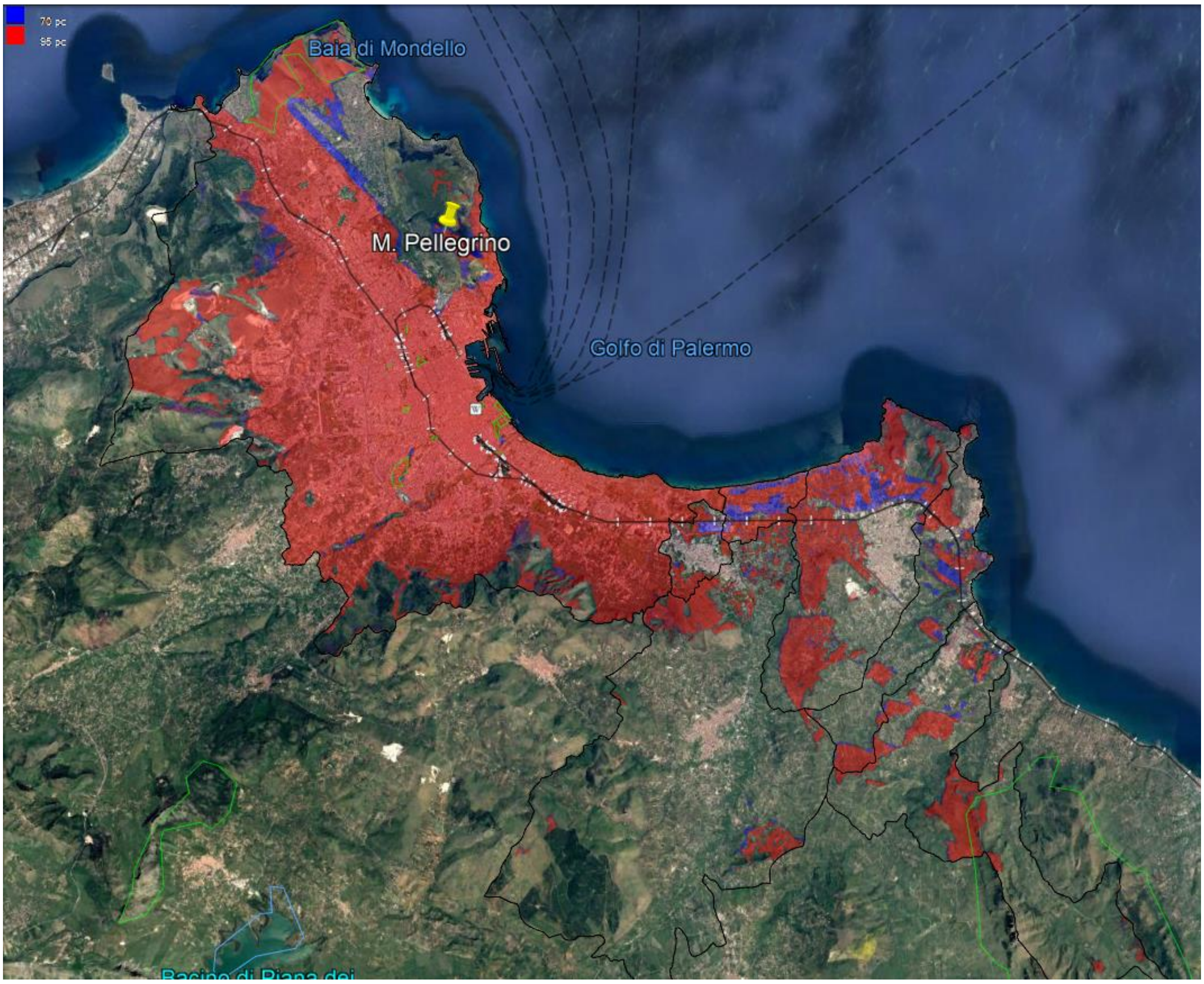
FIGURE 116

Palermo itineraries and travelling speed

The theoretical location probability in the same area is shown in Fig. 117.

FIGURE 117

Coverage of the Palermo area. Red = LP ≥ 95%; Blue = LP ≥ 70%



The results of the trials are presented in Figs 118 and 119. Considering all the paths, the ones inside and the ones outside the service area, the QEF reception scores 90.5% and, if the time of acceptable reception is added, the percentage rises to 91.5%.

If only the urban area of Palermo is considered (therefore excluding the zone to the north / north-west of the transmitter), the percentage of reception is 100%, and it is proved to be optimal even in the narrow streets of the city centre.

These outcomes have been compared to the planning calculations (with an optimal match) and to the measured field strength: the QEF reception is granted in the area where the LP is ≥ 95%, as expected and where the field level is greater than 60 dBμV/m.

Finally, the zones outside the coverage area have been investigated to obtain information on the minimum electromagnetic field level necessary for proper reception.

FIGURE 118

Service quality in the Palermo area

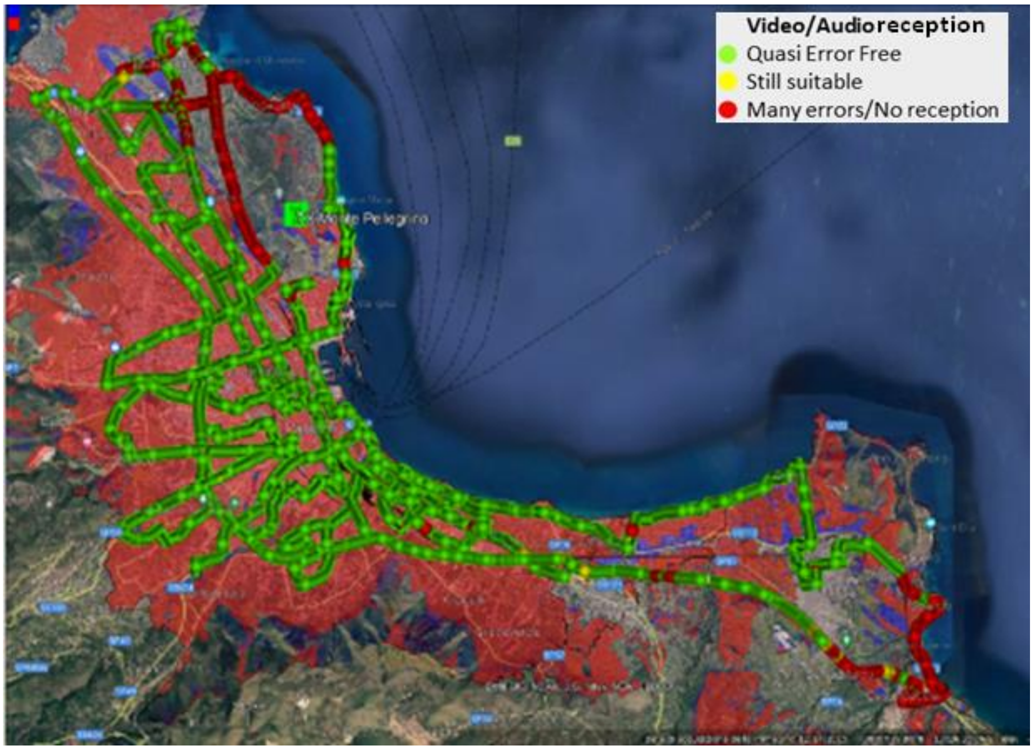


FIGURE 119

Measured field strength in the Palermo area

2.10.2 Turin field tests

Similarly to the Palermo trials, some itineraries have been detected for the area of Turin, too. In this case, 13 different tracks in the centre and on the motorways around the city have been covered for a total amount of 165 km.

Figure 120 displays the routes and the travelling speed.

FIGURE 120

Turin itineraries and travelling speed

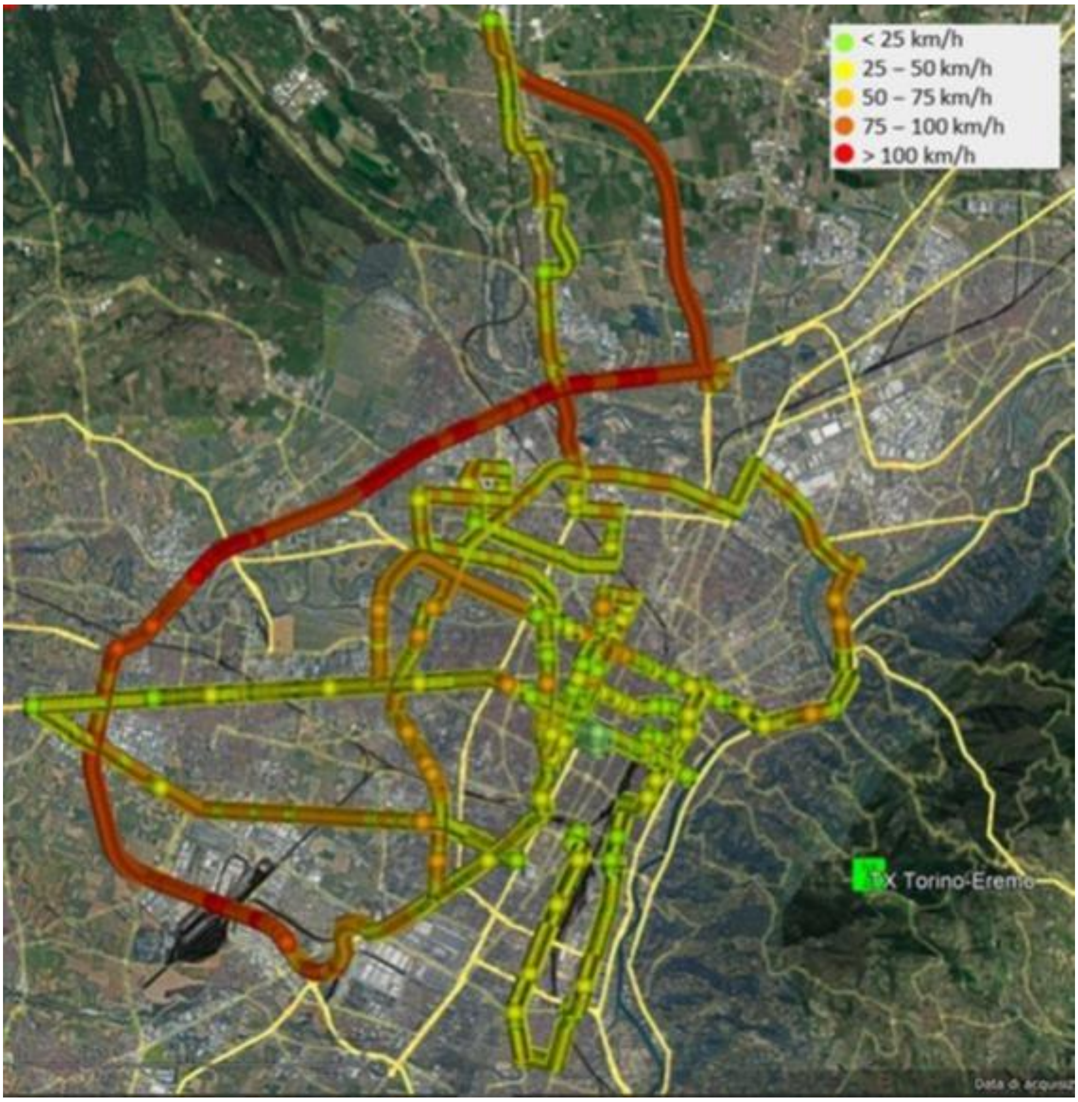
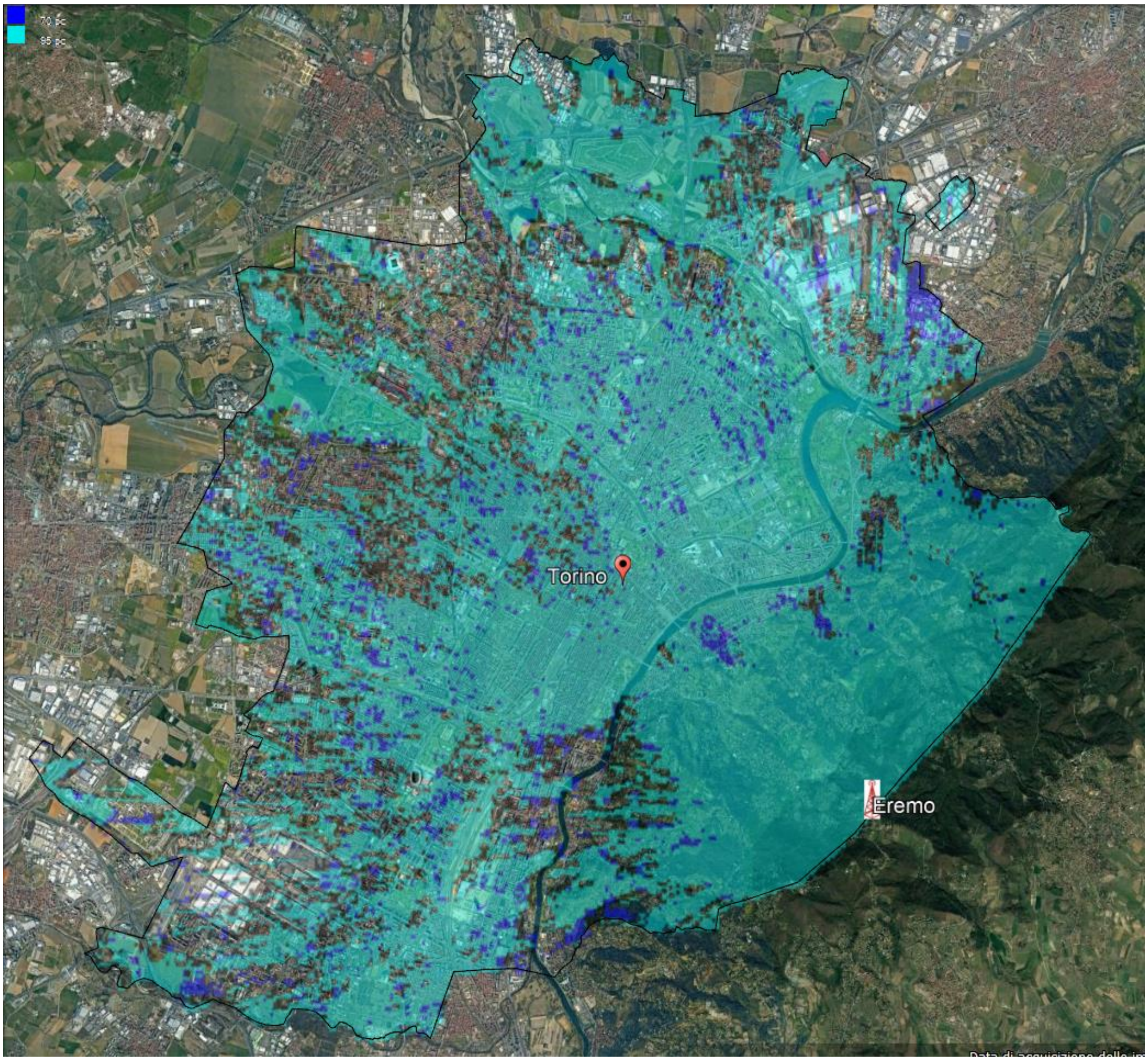


Figure 121 shows the theoretical location probability in the Turin area.

FIGURE 121

Turin coverage. Light blue = LP ≥ 95% – Blue = LP ≥ 70%

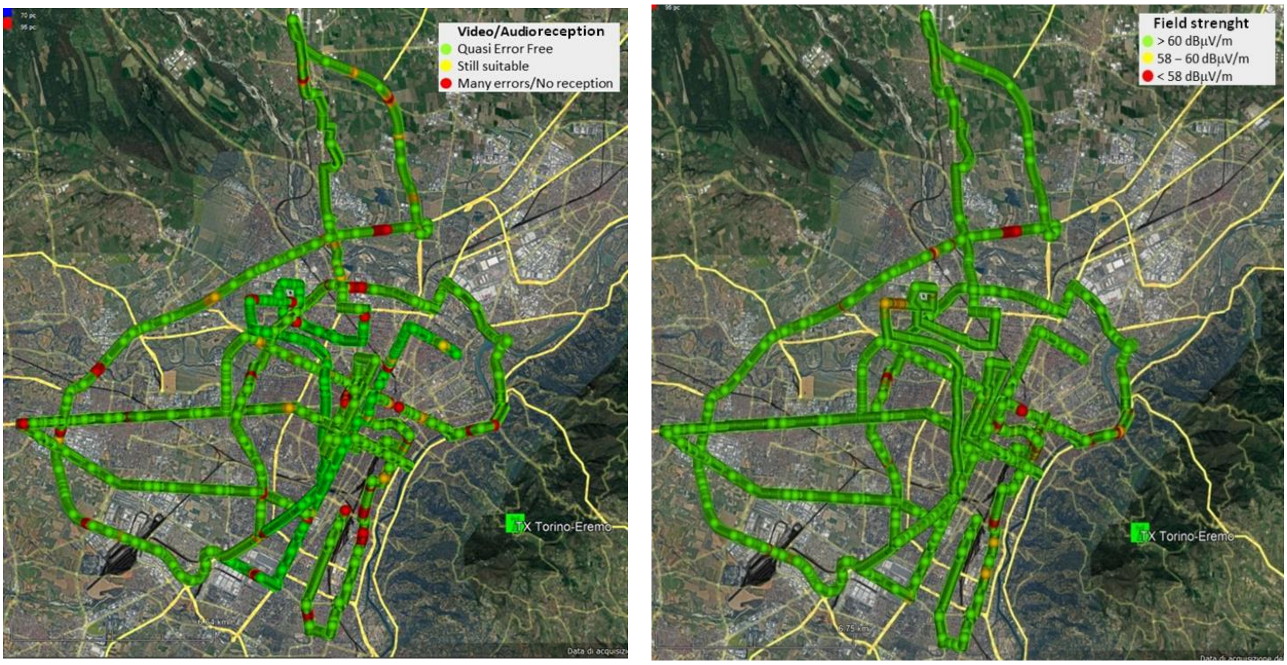


The outcomes of the trials show that the overall QEF reception counts 92.8%. If also the points with acceptable reception are considered, the percentage rises to 96.2%. This evaluation includes some areas outside the service area, such as, for example, the south-eastern part of the city that lies under the hill, where the TORINO EREMO transmitter is located, and it is partially obscured by the hill itself.

In the city centre, the reception is almost everywhere more than acceptable, and only in very few points, in streets particularly narrow and surrounded by very tall buildings, there is no service.

FIGURE 122

Turin area – reception quality and measured field strength



2.11 Field tests with the experimental receiver

One of the stakeholders of this project was the Politecnico di Milano, PoliMI, whose duty was to develop a receiver derived by the “5G-MAG Reference Tools”.

PoliMI carried out several levels of development in order to obtain the desired receiver, starting with the implementation of the reception of DASH/HLS streams in 5G broadcast and unicast mode and then integrating a ‘seamless switching’ functionality. The receiver is composed by a SDR module connected to a laptop.

FIGURE 123

PoliMI receiver

Some field tests have been performed in order to verify the performances of the receiver. The trials have been carried out in mobile mode, using the equipped vehicle of RAI CRITS.

Four different itineraries in Turin, for a total amount of 17 km, have been chosen to test the receiving capability of this prototype. The outcomes show that, in a mobile reception scenario, the performances of the PoliMI receiver are comparable to the professional one used for the entire measurement campaign of the 5G Audiovisual project.

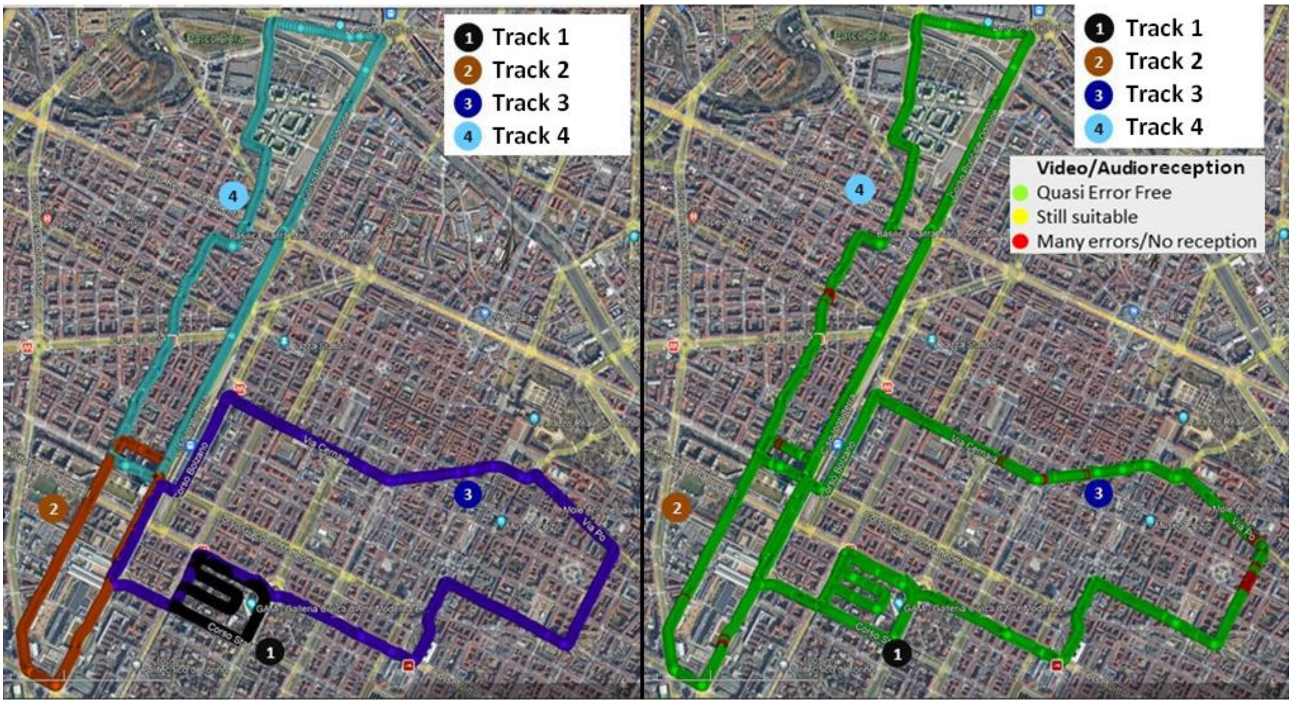
TABLE 38

Percentage of error free reception

Itinerary	Length	Travelling time	Percentage error free reception
Track 1	1.7 km	5 min	100%
Track 2	2.8 km	9 min	97.8%
Track 3	6.7 km	30 min	97.5%
Track 4	5.9 km	15 min	97.3%

FIGURE 124

PoliMI receiver reception capability

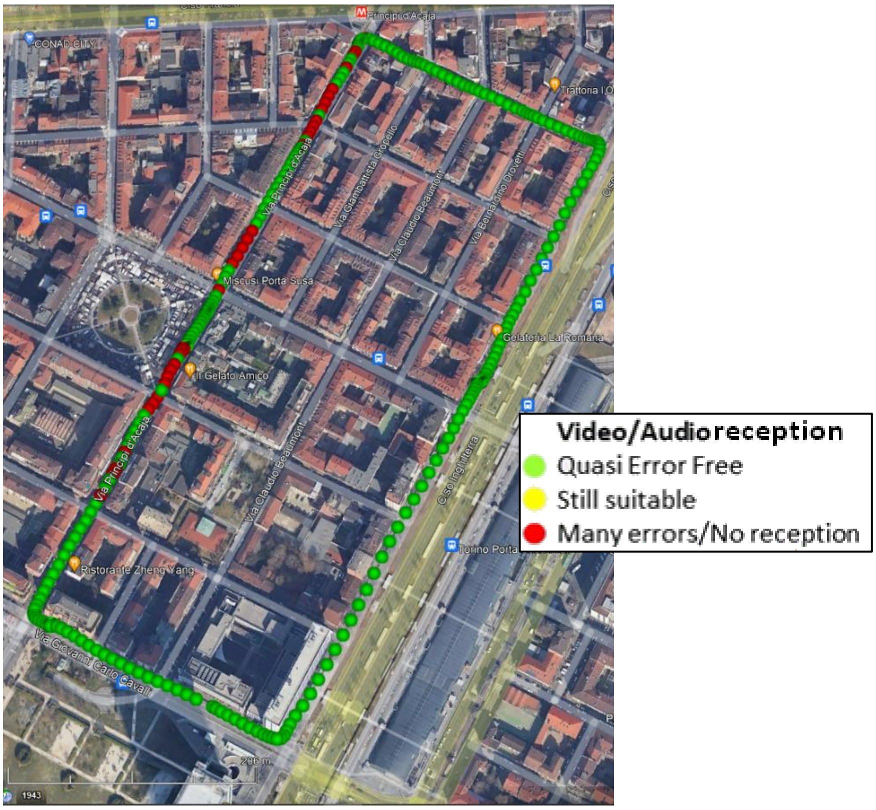


A second field test was carried out to verify the functioning of the seamless switching between broadcast and broadband.

For this purpose, among the itineraries covered for the 5G Broadcast reception check, the most critical track was selected. This choice allowed to stress the performances and the benefits of the switch between broadcast and broadband. The test has been done on a track of 2 km where many errors in the reception of the 5G Broadcast signal have been detected, and 10 dB of attenuation was also added at the receiver input to make it even more critical. In this circumstance, the error free reception percentage of the receiver on the route dropped to a value of 90.5%.

FIGURE 125

Broadcast reception with PoliMI receiver



Then, the receiver has been tested with the functionality "Seamless Switching" switched on, configured as follow: C/N threshold 15 dB; C/N enquiry time 1 second; hysteresis time 10 seconds.

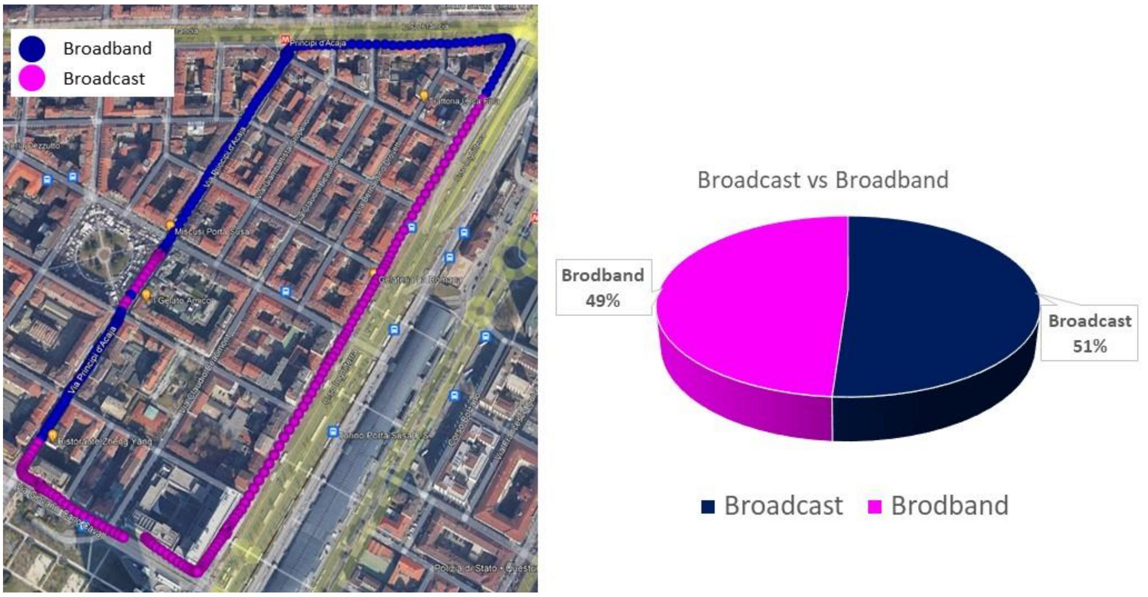
No reception errors have been registered along the track, and in Fig. 127 the percentage of the broadcast and broadband time is shown.

FIGURE 126

Broadcast and broadband reception with PoliMI receiver

FIGURE 127

Broadcast and broadband time



The broadband intervened for 222 seconds, out of 456 seconds of a total lap time, for a required data traffic of 35 MB. Undoubtedly, it is important to minimise the broadband intervention and to limit it only when it is strictly necessary in order to keep data consumption as low as possible. This can be obtained adjusting the required *C*/*N* threshold and the hysteresis time. By lowering the threshold *C*/*N*, the broadband intervenes less, but there is a risk of not intervening in time and thus having some errors in signal reception.

The other parameter that can be adjusted is the hysteresis time, i.e. the minimum time that must elapse between a switch to broadband when the *C*/*N* value goes down the threshold and the reinstatement of broadcast when the *C*/*N* returns above the threshold. This parameter was inserted because in a mobile channel the *C*/*N* has a very high variability and the continuous switch between broadcast and broadband can generate anomalous behaviours of the receiver (blocking and necessary restart). It has been proven that a hysteresis of 10 seconds allows the receiver to be managed correctly. However, it is clear that such a hysteresis time is an additional element that contributes to lengthening the broadband usage.

3 EI-Towers 5G field trial in Lissone (MB – Italy)

3.1 Summary

EI-Towers carried out an LTE-based 5G Broadcast "demo" field test in March 2023 in an area around its headquarters in Lissone (Lombardy).

The intention was to see the functioning of the system in practice, the characteristics of the equipment (BSCC, transmitters, handsets) and present the LTE-based 5G Broadcast system to a range of possible stakeholders in a future service. This includes, between others, broadcasters, content providers, IP carriers and consumer equipment manufacturers.

In particular, one of the achieved objectives was also to take a look at the quality of the radio coverage and the interference aspects with adjacent (downlink) channels used by Mobile Operators. Indeed, for this trial, EI-Towers used one of the three 5-MHz blocks in the 700 MHz duplex-gap band which, in Italy, are called SDL-B1, SDL-B2 and SDL-B3, and in particular, SDL-B1.

The reason for this choice was that these 5-MHz blocks in the duplex-gap of the 700 MHz band remained unsold in Italy after the auction made for the 700 MHz band and, therefore, are available today. Conversely, in Italy, all channels in the UHF band (at least those coordinated with neighbouring countries) are already used for broadcast, making extensive use of SFN networks also with national coverage. Only UHF channels currently assigned to neighbouring countries would be available and, in practice, even one regional coverage would be difficult to achieve.

As a follow-up, the idea would be the possible implementation of an LTE-based 5G Broadcast network with more extensive coverage in one or more Italian regions and/or a number of locations of interest (e.g. football stadiums). In addition, the QoE could also be evaluated with a selected group of users.

3.1.1 Participants

– EI-Towers (I)

– Rohde & Schwarz (D).

3.1.2 Start date and duration

– March 2023.

3.1.3 Location

– Lissone (Monza e Brianza – Lombardy).

3.1.4 Technologies

– 3GPP Release 16.0.

3.1.5 Equipment and infrastructure

– BSCC and TX 20 Watt (operating at 2.5 Watt and 1 Watt ERP) (Rohde & Schwartz)
– Prototype LTE-based 5G broadcast compatible handsets (3GPP Release 13.0)
– TSMA/TSMW 4G/5G receivers and SW ROMES (Rohde & Schwarz).

3.1.6 Spectrum and frequencies

– 5 MHz, 738-743 MHz band – SDL-B1.

3.2 Main goals

The intention was to see the functioning of the system in practice, the characteristics of the equipment (BSCC, transmitters, handsets) and present the LTE-based 5G Broadcast system to a range of possible stakeholders in a future service. This includes, between others, broadcasters, content providers, IP carriers and consumer equipment manufacturers.

3.3 Highlight

Contents

The contents were prerecorded sequences in MPEG-TS format with H264 video coding (MPEG-4/AVC), live content (Channel 5, DAZN Zone, Cartoonito) in MPEG-TS over IP format with H264 video coding, or prerecorded content in DASH format with H264 video coding. Video signals were 720p or 1080p with 50fps.

The audio/video bit rate (in the live case) was identical to that transmitted on the DTTB or IP platform and of the order of 3 to 4 Mbit/s. For pre-recorded sequences it was of the order of 3 Mbit/s. Some live signals were also prepared with a reduced bit rate of 1 Mbit/s in order to be able to use MCSs with less capacity.

With regard to the unidirectional transport of the signal (via the ROUTE protocol, formerly FLUTE of DVB-H), the choice of mode was made taking into account first of all that the 3GPP standard provides for the following two types:

– file-based: this can be used by OTT services (DASH/HLS) for the distribution of videos or for the distribution of files (e.g. firmware updates or other);
– streaming: this can be used for the distribution of live video with low latency or other, and the RTP protocol is an example, not necessarily audio/video.

Note that file-based distribution per se does not introduce latency (apart from the time it takes to download the file), but it is then the video distribution protocol (DASH/HLS) that generates it. For example, the HLS player will not start playing the content unless it has downloaded at least three segments, and since a segment typically lasts 3 to 5 seconds, there will therefore be at least 10 to 15 seconds of latency. In the course of the experiment, the choice to use one mode rather than another was therefore constrained by the support of the phone and the resident video player app.

In this case, in addition to DASH/HLS, RTP was supported and therefore this protocol was chosen to have the minimum delay.

In conclusion, the LTE-based 5G Broadcast delay of live transmissions was in line with that of the DTTB platform and, compared to the equivalent OTT service[7], about 15 to 20 seconds earlier.

Figure 128 shows a picture of one of the phones used during the experiment.

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[7] OTT stands for 'Over the Top', a multimedia service offered directly to viewers via the Internet.

FIGURE 128

Photo of the LTE-based 5G Broadcast phone

Transmitter

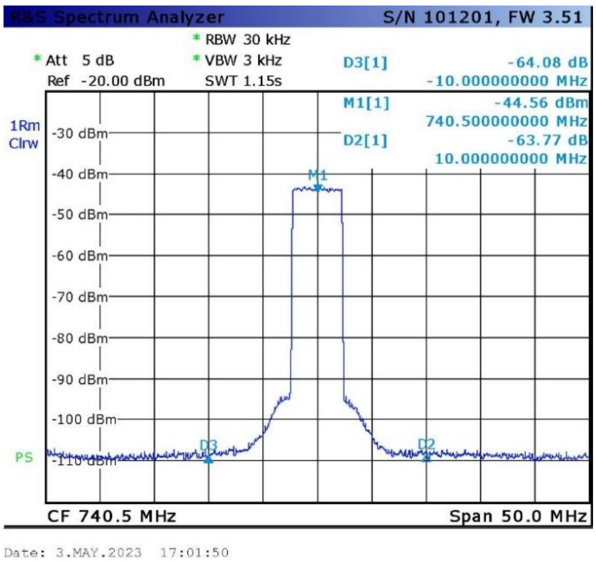
The transmitter was used with 2.5 W of output power (before the filter) and 1 W ERP.

Figure 129 shows the spectrum measured at the output of the transmitter with a simple non-critical mask) four-pole filter.

It is a filter usually used in DTTB stations and re-calibrated for the occasion at 740.5 MHz centre band and 5 MHz bandwidth. In this case the attenuation is more than 60-63 dB on adjacent channels and also out-of-band, more than 100 MHz away from the 740.5 MHz centre frequency.

FIGURE 129

Example of TX spectrum with channel filter



For reception, the following equipment was used:

– 2 Qualcomm LTE-based 5G Broadcast phones supplied by R&S, capable of demodulating the LTE-based 5G Broadcast signal and presenting audio and video.

– R&S TSMW and TSME receiver with R&S ROMES software.

– R&S ETL spectrum analyser (and DTTB receiver).

– Omnidirectional antenna, Pol.V for mobile reception.

Measurements were conducted on the move, using the TSMW/TSME receiver with the Romes SW and the telephone (in-car reception) and also while stationary (out-door reception), using the telephone and checking the possibility of receiving the A/V signal.

Figure 130 shows an example of the spectrum of the signal received in the field. Specifically, the image includes the spectrum from 720 to 790 MHz.

Figure 131 shows the quality of LTE-based 5G Broadcast coverage. The position and direction of the cell are indicative. For the useful LTE-based 5G Broadcast service, it can be concluded that the extent of useful outdoor coverage (signal level at 1.5 m) for MCS10 is limited to about 400 m at most and is very similar to that envisaged at the application stage.

FIGURE 130

Example of (received) spectrum in the field

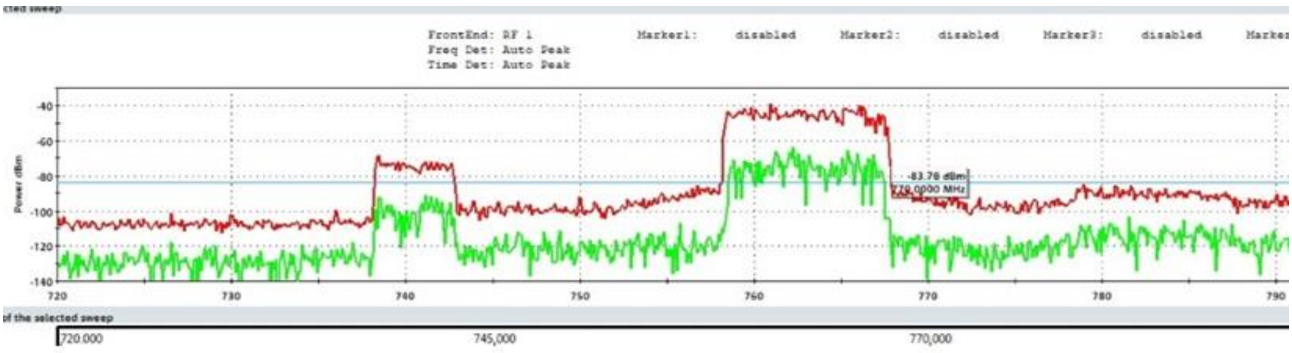
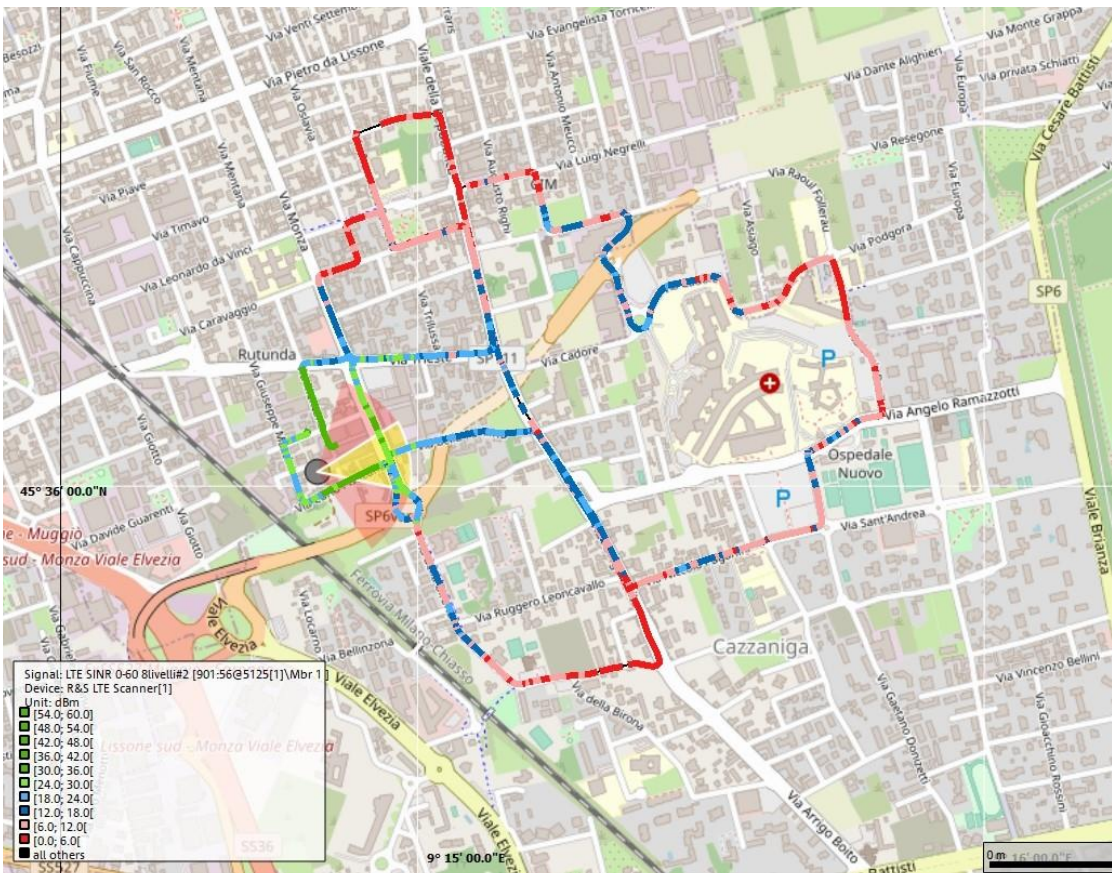


FIGURE 131

Quality of LTE-based 5G Broadcast coverage



3.4 Summary of some results of the demo

– LTE-based 5G broadcast works properly and with low latency compared to the corresponding 'unicast' OTT service. In fact, live transmissions are in line with DTTB transmissions and about 15 to 20 seconds earlier than the equivalent OTT 'unicast' service when using the RTP protocol in the 5G broadcast system, as chosen during the DEMO.

– The LTE-based 5G Broadcast system was successfully presented to a good number of stakeholders interested in a possible future service. These included content providers, TV broadcasters, IP operators and equipment manufacturers.

– The coverage, in terms of received em. field E is as expected, based on the estimated characteristics of the measurement system (receiving antenna, drop cable and professional receiver):
  - Moreover, this coverage is very small, given the very limited transmitter power.
  - For real operation, a transmission power of an order of magnitude or more is appropriate (e.g. 20 W ERP instead of 1W ERP).
  - A greater height of the transmitting antenna, e.g. at least 30-40 m, would greatly facilitate the extension of coverage, especially in the presence of obstacles (clutter). This assumption is made on the basis of simulations performed by modifying this height.

– No difference in coverage quality was measured on the adjacent bands (Mobile Network Operator service in downlink, B28) in the presence of the LTE-based 5G Broadcast signal compared to when such a signal was not present.

– The phones used in the trial, at least for now, only work without a SIM i.e. as small ‘televisions’ but with all the functionality that a Wi-Fi can offer and, at least for the time being, still work only with an old release of the specification.

– It was possible to gain important experience with regard to the coding of audio/video content for portable and mobile services and also with regard to the measurement of the mobile radio service, both in terms of the level and quality of radio coverage of the individual frequency band and of each transmitting ‘cell’.

4 LTE-based 5G broadcast trial of a broad SFN coverage in the Milan and Palermo Area (2023/2024)

4.1 Summary

The objectives of the trial were to determine whether it was possible to reuse existing signal transport networks, verify the correct operation of the network in SFN, examine some aspects of radio coverage forecasting models and, finally, evaluate the network’s performance in terms of quality, coverage extension and service compatibility with adjacent radio channels.

At this regard, also some measurement at the border with Switzerland were foreseen, to evaluate the co-channel compatibility of the 5G-Broadcast service with a neighbouring country.

In a first phase, the characteristics of the individual devices and the overall network architecture (signal generation, transport, and reception) were assessed. A network was then created consisting of three SFN transmitters, serving a vast area of Lombardy, including Milan, plus a transmitter serving Palermo and a large portion of the Tyrrhenian coast northeast of the city. This latter transmitter was developed in collaboration with TGS (Telegiornale di Sicilia), a project partner.

4.1.1 Participants

The trial was a part of a larger project, named 5G M&B (5G Mobile & Broadcast) led by EI-Towers and involving numerous other Companies and Institutions (Politecnico di Milano, RTI Mediaset, Vodafone, Università di Palermo, TGS, Comune di San Vito lo Capo, U4learn, Elk, Pay4D, Feedback), with the funding and patronage of MIMIT (Italian Ministry).

4.1.2 Start and conclusion date

Started in August 2023 and concluded in November 2024.

4.1.3 Location

Transmission in Palermo and Milan with the coverage of a wide area of the "Pianura Padana" in Lombardy.

4.1.4 Technologies

3GPP Rel. 16 5G Broadcast SFN feature set on top of 3GPP Rel. 12 eMBMS (release currently available in commercial smartphone).

4.2 Equipment and infrastructure

– Transmission equipment varied, depending on test-bed location
  - One BSCC (5G Broadcast Core network) located in Lissone at EI-Towers premises.
  - Two HPHT sites, one in Palermo (M.te Pellegrino) and one near Milano (Valcava), and two MP-MP sites, one in Milano (Milano Repubblica) and another near Milano (Lissone EI-Tower), all based on Rohde & Schwarz LTE-based 5G broadcast technology such as BSCC.
– Distribution of the signal by satellite and by fibre/radio link network as redundancy.
– Precision Wave BR-VBI receiver with Kathrein Software and Hardware/Software defined receiver (SDR) by Rohde & Schwarz for 5G-Broadcast measurement purposes. Additional receiver by R&S for LTE/5G measurement purposes.
– Prototype 5G Broadcast-compatible handsets (rel.12 of the specification only).

4.3 Spectrum and frequencies

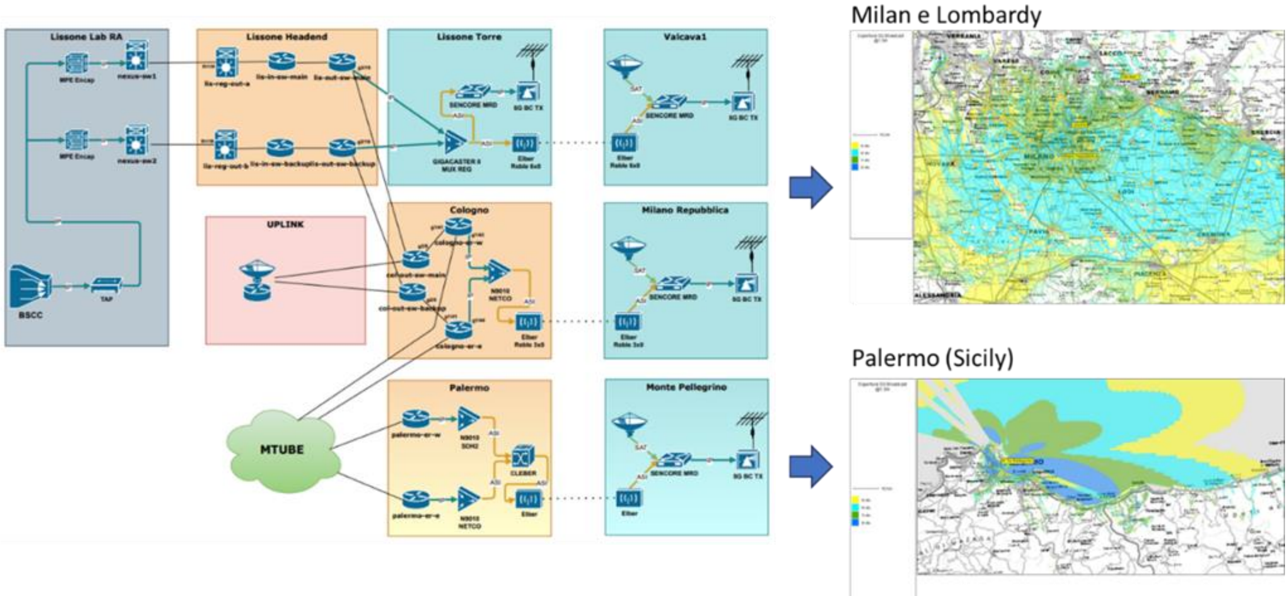
– 700 MHz SDL Band (duplex gap inside LTE band 28 at 700 MHz), 5 MHz channel bandwidth – channel centre frequency (CF) dependent on the test-bed location.
  - Milan: LTE band 67, CF = 740.5 MHz (SDL-B1).
  - Palermo: LTE band 67, CF = 745.5 MHz (SDL-B2).

4.4 Distribution network description

Figure 132 shows the block diagram of the signal transport network. It reuses the same infrastructure of the DVB-T networks and, therefore, one ISI inside a DVB-S2 satellite link and network sections in radio link and fibre optic networks. The existing infrastructure is transparent to the transport of the 5G-B signal in SFN to the transmitting sites and only MPE adaptation is needed.

FIGURE 132

Block diagram of the signal transport network

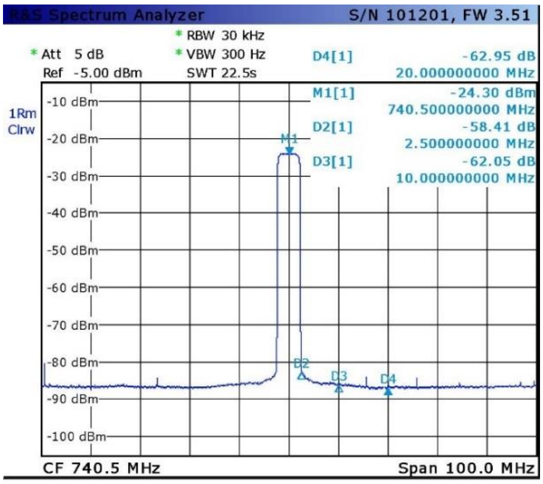


4.5 On-site measurements

As a preliminary example, Fig. 133 shows the (excellent) result of the measured spectrum after the filter at the Lissone-EIT transmitter (20 Watt).

FIGURE 133

Lissone EIT transmitter with output filter (span 100 MHz)



4.6 Main results of the trial

The 5G-Broadcast signal transport and distribution architecture are also consolidated in SFN mode and for Release 16 of the specification.

Existing signal distribution infrastructure can be used and the coverage of any site reached by the transport network can be easily added to the 5G-B SFN network.

Correlation ("fine tuning") of field measurement results with coverage forecasts has allowed to optimize the coverage calculation model. This work may continue in the future to obtain further results useful for computer simulations.

With current transmission power levels, 5G Broadcast does not cause any interference to services operating on adjacent bands (e.g. DL at700 MHz) and it is conceivable that this will also be true for a potential 5G-B service in the UHF band. The compatibility of 5G-B in the SDL band with the UL portion of the 700 MHz band could be further explored, but no problems are expected, given the excellent characteristics of the 5G-B transmitters and filters.

Forecasts and measurements suggest that the impact of the 5G Broadcast service beyond the Swiss border is extremely limited and could be further reduced by appropriately modifying the transmitting antennas. All of this is without prejudice to the priority use of each of the SDL channels by Italy or Switzerland.

It is also believed that the current power of the systems used for 5G-B testing could be increased and, for example, match that used for Digital Terrestrial, thus improving useful coverage without creating compatibility issues with adjacent and cross-border services.

Main transmission sites are always necessary for broad coverage. The choice of whether to integrate them with other broadcast sites, MNO sites, and/or a hybrid unicast service depends on the coverage objectives (area, number of potentially reached inhabitants, network complexity, bit rate, coverage quality, etc.). Some useful indicators for preliminary quality and cost assessments are already available. In this regard, see also EBU TR 063 [1].

It is necessary to have a sufficiently accurate (and advanced) knowledge of the RF characteristics of future real UEs (User Equipment) to optimally design networks.

4.7 References

[1] EBU Tech Report 063, "5G Broadcast Network Planning and Evaluation" (rev.1, Jan 2025).

5 LTE-based 5G broadcast pre-commercial service and trials in major Italian cities (2024/2025)

5.1 Summary

5G Broadcast is a distribution solution with wide-ranging applications – particularly suitable to deliver live content to large audiences on the move, complementary to mobile broadband. It enables users to access free-to-air broadcasts without needing a SIM card, without registering for external services, and with notable efficiency benefits for content distribution networks.

Rai-CRITS has conducted comprehensive laboratory evaluations and field trials to assess LTE-based 5G-Broadcast features, as specified in 3GPP Release 14 [1], Release 16 [2], and subsequent updates [3,4] enabling adaptation to the UHF broadcast band for mobile device reception. These tests focused on evaluating coverage and Quality of Experience (QoE) across urban, dense urban, suburban and rural environments.

Since the end of 2024, Rai has been airing the first large-scale pre-commercial 5G Broadcast service to exploit the reception of live content to audiences in major Italian cities.

On November 4th, the transmissions were activated in the metropolitan areas of Rome and Turin, using dedicated bandwidth in UHF TV spectrum, identified and assigned by the Italian Ministry for experimental purposes. These experimental broadcasts are continuously available for content consumption and technical test campaigns to devices equipped with the 5G-Broadcast functionality. The project plans to extend the transmission to other additional major cities in Italy, in order to showcase the potential value this technology can offer to the media industry and millions of viewers.

5.1.1 Participants

– RAI (Public Service Media Organization – TV Content Provider) (www.rai.it) – EBU member.

5.1.2 Start date

– November 2024.

5.1.3 Location

– Transmission in operation in Turin and Rome.

– Plans to extend to Palermo, Milano and Napoli.

– Plans to extend to Cortina, during the Winter Olympic Games 2026.

5.1.4 Technologies

– 3GPP Rel. 16 5G Broadcast feature set on top of 3GPP Rel. 12 eMBMS (release currently available in commercial smartphone).

5.2 Equipment and Infrastructure

– Transmission equipment varied, depending on test-bed location:
  - One BSCC (5G Broadcast Core network) located in RaiWay Data Centre (Rome).
  - Two HPHT sites, one in Turin and one in Rome, based on Rohde & Schwarz LTE-based 5G broadcast technology.

– Hardware/software defined receiver (SDR) by Rohde & Schwarz and iFN (for measurement purposes).

– Prototype 5G Broadcast-compatible handsets (Xiaomi, Motorola, OnePlus).

5.3 Spectrum and frequencies

– 600 MHz band, 5 MHz channel bandwidth – channel centre frequency (CF) dependent on the test-bed location:
  - Turin: LTE band 71, CF = 619.5 MHz
  - Rome: LTE band 71, CF = 649.5 MHz

5.4 Pre-commercial service: distribution network description

In the second half of 2024, after being involved for about ten years in experimental activities, Rai activated the first Italian 5G Broadcast (5G-BC) pre-commercial service for mobile outdoor reception. According to the original plans, this service activation involves 5 Italian metropolitan areas, covering about 16 million potential customers. A simple network infrastructure scheme is provided in Fig. 134.

FIGURE 134

Network infrastructure

The central node is located in Rome, at Rai Way Monte Mario transmitting site, where the following equipment has been installed:

– 1 A/V encoder, providing a statistical Multi Program Transport Stream (MPTS) with up to four HD channels (HEVC encoded);
– 1 5G-BC core network, including:
  • BM-SC (Broadcast Multicast Service Centre);
  • MBMS-GW (Multimedia Broadcast Multicast Service Gateway);
  • MCE (Multicast Coordination Entity);
– 1 5G-BC transmitter (TX), covering the metropolitan area in Rome.

As a first step, it was decided to transmit a Transport Stream (TS) because, having a very low delay compared to DASH and HLS, and not having particular requirements in terms of player capabilities, it simplifies the testing procedures[8].

The 5G-BC TXs in the other four cities part of the network, Turin, Milan, Naples and Palermo are fed by the central core network via IP connections.

As of May 2025, the transmitting sites of Turin-Eremo and Rome-Monte Mario are active, distributing three programs over the air (Rai News 24, Rai Radio2 Visual and Rai Teche). Transmitters and radiant systems in Turin and Rome have different characteristics, according to the permissions granted by the Italian authorities (Fig. 135) but they share the modulation parameters, as shown in Table 39.

8 The encoder can generate any format: TS, DASH and HLS.

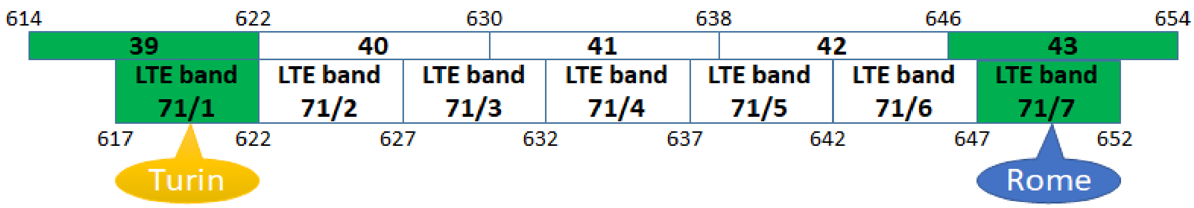
TABLE 39

TX characteristics

	Turin	Rome
Site	Eremo	Monte Mario
Nominal power	500 W	125 W
Centre frequency	619.5 MHz	649.5 MHz
Polarization	V	H
Bandwidth	5 MHz	
MCS	12 (16 QAM – rate 0.42)	
Sub carrier spacing (SCS)	15 kHz (Rel. 12 compliant)	
Release	3GPP eMBMS Rel. 12 compliant	
Total useful bitrate	2.95 Mbit/s	

FIGURE 135

Frequency plan in Turin and Rome



Although the name 5G Broadcast (5G-BC) identifies versions of the 3GPP standard from Release 16 onwards, it has to be taken into account that at the moment the only available receivers with a smartphone form factor are based on 3GPP eMBMS Rel. 12, modified to include some of the main features of 5G-BC, in particular the receive only functionality and operability in the n71 band, corresponding to the lower part of the 600 MHz band of the UHF spectrum.

5.5 Service area measurements

An extensive outdoor measurements campaign is being carried out both in Turin and in Rome, to evaluate the coverage of 5G-BC services in the following use cases:

1 Pedestrian outdoor

2 Mobile in-car

For the first time since Rai have been involved in 5G-BC activities, real smartphones from three different brands are available. In order to be compliant with 5G-BC reception, the smartphones had to be properly modified with the authorization of the manufacturers[9]. A specific mobile App (Rai moTV, see Fig. 136) with Rai layout has been installed to watch 5G-BC TV services.

[9] This modification currently limits the ordinary 5G functionality.

FIGURE 136

Rai moTV app

For the measurement campaign in the use cases defined above, a specific software (ALC meter) has been designed and implemented by Rai CRITS, capable of recording in real-time an indication of the received video quality as perceived by the operator, logged according to some preconfigured criteria such as the number of signal impairments detected in an observation window (in metres or seconds). The software also associates each recorded value to the geographical position by means of a GPS receiver, for either instant plotting over an XY diagram or offline over a real map (i.e. Google Earth). Depending on the preconfigured quality scale, the plotted values are associated to different colours (i.e. green for "Quasi Error free", yellow for "Still suitable", red for "Many errors/No reception").

It has to be taken into account that coverage results are partially affected by measurements "non-repeatability", since the environment around the operator cannot be always the same because of too many variables (traffic, temporary obstacles, position in the street, orientation with respect to the transmitter, etc.).

The measurement campaign in major cities (large urban areas) is currently underway, with plans to cover the metropolitan areas of Turin and Rome. Pedestrian outdoor and drive-test campaigns will be conducted in both cities to gather performance data, assess achievable coverage, and identify network configuration requirements necessary to ensure a satisfactory Quality of Service (QoS).

The tests in the metropolitan area of Turin and Rome will allow to evaluate the performance of the system in a densely populated area, characterized by the presence of tall buildings and other obstacles which often prevent a receiver from having the direct view of the transmitting site. Tests in the two cities, where different polarizations (horizontal and vertical) are used, will further allow to verify the impact of transmission polarization on the performance that can be achieved.

Preliminary results indicate the readiness of the technology. The outcome of the measurement campaign will be included in a future update of this report.

5.6 References

[1] 3GPP TR 38.913 v14.3.0, "Study on scenarios and requirements for next generation access technologies", August 2017.

[2] 3GPP TR 36.976 v16.0.0, "Overall description of LTE-based 5G terrestrial broadcast", March 2020.

[3] ETSI TS 103 720 v1.2.1, "5G Broadcast System for linear TV and radio services; LTE-based 5G terrestrial broadcast system", June 2023.

[4] ETSI TS 136 101 v18.7.0, Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) radio transmission and reception (3GPP TS 36.101 version 18.7.0 Release 18, October 2024).

Annex 6

LTE-based 5G terrestrial broadcast field trials in Denmark

1 Copenhagen trial

1.1 Summary

In June-July 2022, during the opening week of the Tour de France 2022, an LTE-based 5G broadcast trial was established in Copenhagen.

The trial was realized through a collaboration between the Danish Broadcasting Corporation (DR), TV2 Denmark, Rohde & Schwarz, Qualcomm, Cibicom, Open Channel and Progira. The programme content was provided by the 5G RECORDS project through TV2, and was produced through a 5G-based live production chain. The trial therefore marked the first time that a full "glass to glass" 5G programme production/broadcast chain was in use.

One purpose of the trial was to test the viability of an LTE-based 5G broadcast implementation using as much existing infrastructure as possible. The LTE-based 5G broadcast transmitter was therefore installed at an existing DTTB-site BOA (Borups Allé) in Copenhagen, where it could be connected to the already established combiner and antenna system, running in parallel with the existing DVB-T2 network on a separate channel, however limited to 5 MHz due to limitations of the receiving device / 3GPP release 16/14. Since DVB-T2 coverage of Copenhagen is provided by four transmitter sites, while only one site was employed for LTE-based 5G broadcast, the power of the LTE-based 5G broadcast transmitter was increased to 8 kW ERP from the 2 kW ERP of the DVB-T2 transmitters on the same site.

Video: LTE-based 5G broadcast Trial in Copenhagen www.youtube.com/watch?app=desktop&v=iV8l52leT9Q

1.2 Participants

– Danish Broadcasting Corporation (DR) – EBU member
– TV2 Danmark A/S – EBU member
– Rohde & Schwarz GmbH & Co. KG
– Cibicom A/S
– Open Channel ApS
– Progira Radio Communication AB
– Qualcomm Technologies Inc.

1.3 Services

– Linear tv programme.

1.4 Start date and duration

– June to July 2022.

1.5 Location

– Copenhagen.

1.6 Technologies

– LTE-based 5G terrestrial broadcast (Release 16).

1.7 Equipment and infrastructure

– Medium power/medium tower transmitter site in Copenhagen; ~10 dBd antenna system gain
– R&S TMU9evo LTE-based 5G broadcast transmitter
– R&S BSCC headend
– Ffmpeg based media converter
– Qualcomm UE devices (support rtp and DASH stream and 15 kHz subcarrier spacing)
– 5G MAG software-based receiver platform with SDRPlay RSP1a RF front end.

1.8 Spectrum and frequencies

– 5 MHz carrier in UHF channel 39 (617-622 MHz) – LTE band 71
– Centre frequency: 619.5 MHz
– 750 W RF output power
– 8 kW ERP
– Antenna height: 97 metres above ground level.

1.9 Main goals

– Verification of the capability of LTE-based 5G broadcast to provide indoor coverage of linear media services for handheld devices
– Proof of concept for reuse of existing DTTB antenna systems for 5G broadcast
– Trial of the 5G-MAG Receiver Reference implementation.

1.10 Highlights

A Rohde & Schwarz LTE-based 5G broadcast transmitter was installed at an existing DTTB site BOA in Copenhagen, sharing the antenna system with five DVB-T2 transmitters. The transmitter had an RF output power of 750 W, leading to a radiated power of 8 kW ERP from a height of 97 metres above ground.

The R&S BSCC headend at the Tx site BOA received a rtp stream via the Cibicom fibre network from a 5G production established by TV2 in Tivoli in Copenhagen and signalled through their playout centre from TV2’s broadcast centre in Odense (Kvægtorvet).

FIGURE 137

The 5G production and broadcast chain, as implemented during the trial

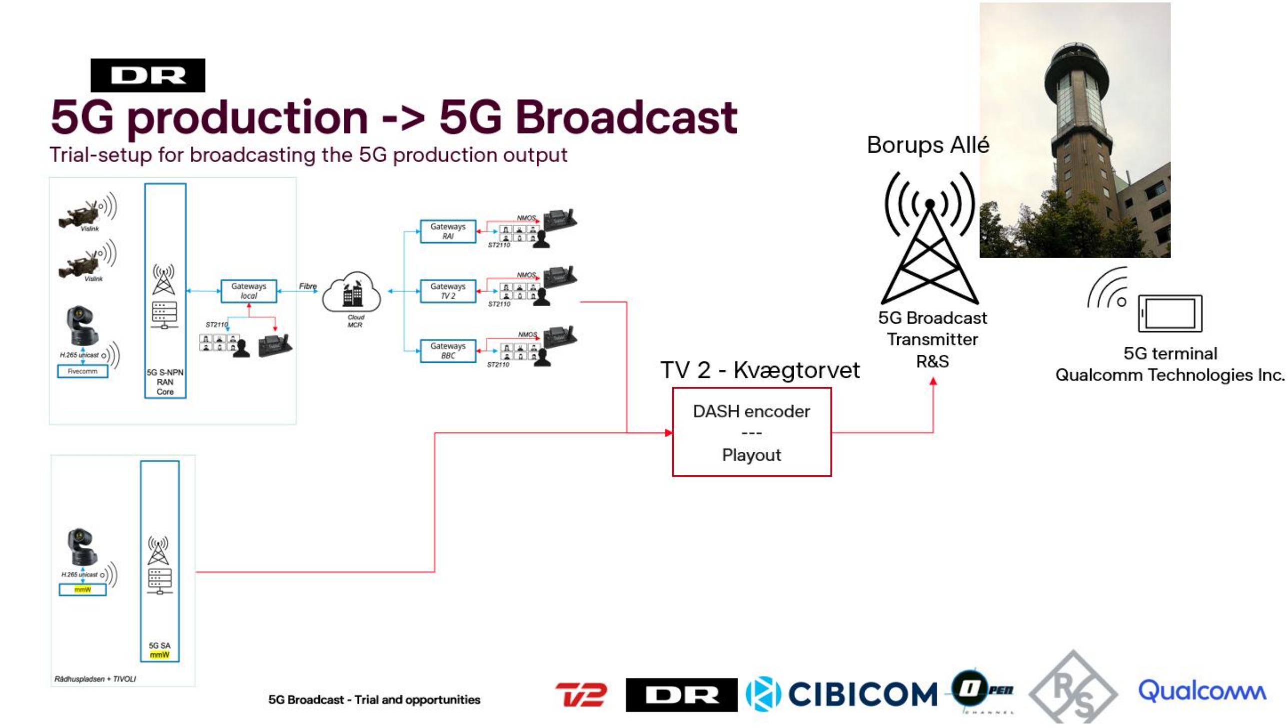


FIGURE 138

LTE-based 5G Broadcast transmission site in Copenhagen

A variety of transmitter configurations were trialled. For the main event a robust modulation scheme (MCS6) was selected to achieve deep indoor coverage. In the 5 MHz channel employed, this gave sufficient bandwidth for a 1 080p rtp-stream at ~1.5 Mbit/s.

The signal was received on Qualcomm prototype End User Devices, and the broadcast content was delivered from TV2 as part of the 5G Records-project, produced through a 5G Private Network production chain.

The intended reception spot was in the conference rooms of the Confederation of Danish Industry, a little over 2.6 km from the transmission site and immediately next to Tivoli, where the Tour de France team presentations were filmed and produced through the 5G Records 5G chain.

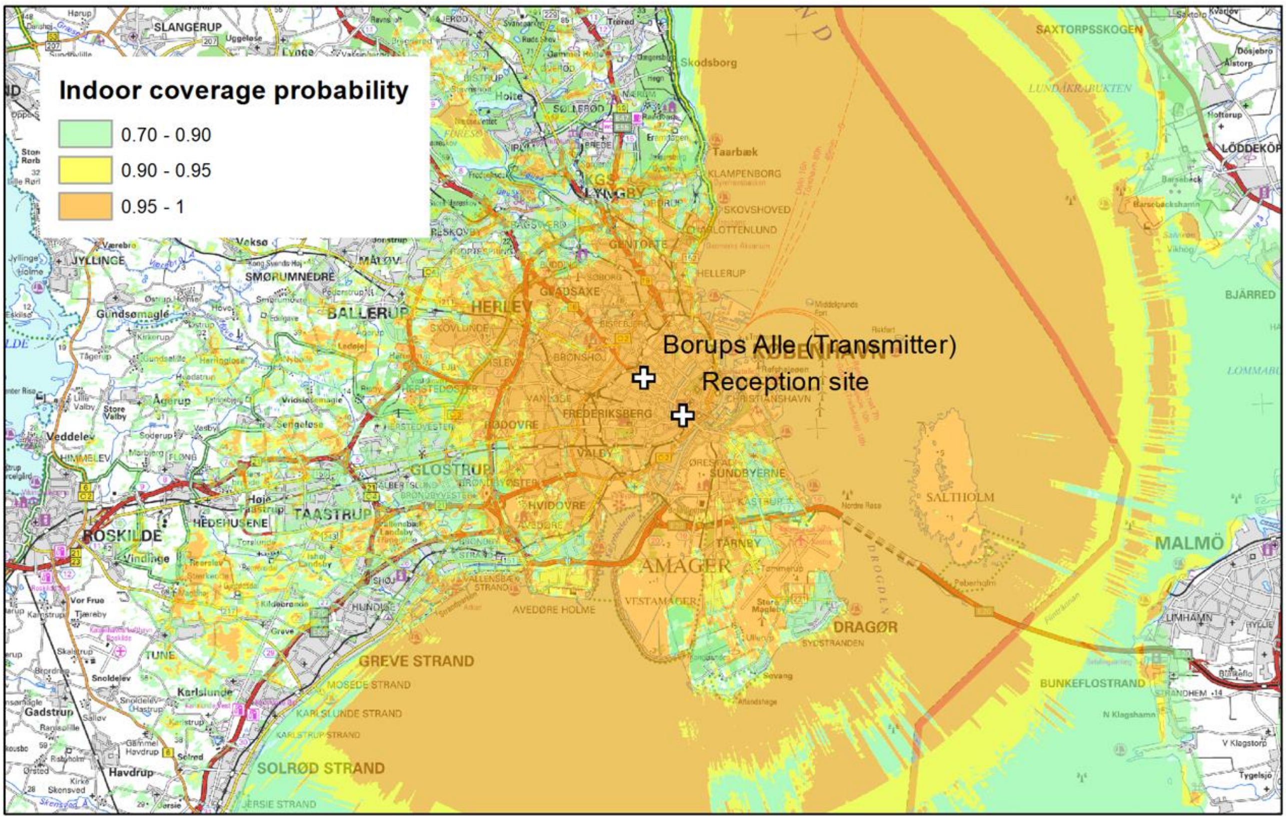
Reception conditions were difficult, since the rooms were on the ground floor of an 8-storey building of low-energy construction with very high building penetration loss. A successful demonstration was still achieved due to the robust modulation and coding scheme employed.

FIGURE 139

"Industriens Hus"; the intended indoor reception spot for the trial

FIGURE 140

Calculated coverage probability (indoor coverage) by Progira



1.11 Take aways from the trial

– Easy setup of LTE-based 5G broadcast transmitter with minimum impact on existing infrastructure.

– Deep indoor coverage in urban environment with LTE-based 5G broadcast to handheld devices (UE) and HD-quality streaming is possible.

– Removal of limitations in UE could probably improve both capacity and coverage (e.g. running 8 MHz block instead of 5 MHz).

– Highly capable SDR-based receivers are available as Free/Open Source software, and can be used with off-the-shelf hardware for receiving, characterizing and logging LTE-based 5G broadcast signals on air.

– Great willingness from industry partners to make the trial a success and a lot of interest in the trial in general.

Annex 7

Spain: LTE-based 5G Broadcast trial in Barcelona

1 LTE-based 5G Broadcast trial in Barcelona during MWC23

1.1 Summary

The efficient deployment of next-generation connectivity is essential to drive technological innovation and accelerate inclusive economic growth. One of the innovation pillars in broadcasting is the efficient transmission of audiovisual contents to mobile phones. LTE-based 5G broadcast will allow viewers to enjoy live content on their mobile phones with low battery consumption and without the need to consume data from the mobile operator commercial network.

During the events of ISE (Integrated Systems Europe) and MWC (Mobile World Congress) in Barcelona a LTE-based 5G broadcast trial was deployed using a 3 KW e.r.p. emission. This trial was the result of the effort of RTVE, Rohde & Schwarz, Qualcomm Technologies and Ateme in collaboration with Cellnex. Cellnex deployed a new transmitter in a location providing coverage to Fira Gran Via venue and its surroundings; the transmitter was provided by Rohde Schwarz; using ATEME encoding solution; and the receivers used for the demonstration had Qualcomm technology.

The configuration used eMBMS (Release 12) with MCS16 (16-QAM) achieved 4.5 Mbit/s of capacity. The capacity was limited to 60% due to performance of Qualcomm reception device.

The content initially included two TV services (including HD) and one Radio service, in a second stage three TV and two Radio services. The content to which there was access included programs from Radio Televisión Española (RTVE): the main channel “La1”, “Canal 24h” and the regional radio channel “Radio 5” and from *Corporació Catalana de Mitjans Audiovisuals* (CCMA) with main channel “TV3” and radio channel “Catalunya Radio”.

The main goal of the trial was to showcase how the full value chain works, from taking the signal to watching the content on a mobile device. The impact of the parameters like MCS on the reception was measured in order to get a better basis for network planning.

1.2 Participants

– Cellnex Telecom – Broadcast Network Operator – EBU member, (https://www.cellnex.com)
– RTVE – National Public Content Provider TV & Radio – EBU member (http://rtve.es)
– CCMA – Regional Public Content Provider TV & Radio (http://ccma.cat)
– Rohde & Schwarz (https://www.rohde-schwarz.com)
– Ateme (https://www.ateme.com)
– Qualcomm Technologies (https://www.qualcomm.com).

1.3 Services

– Linear TV and Radio services (DASH). Test with:
  • 2 TV services + 1 Radio service
  • 3 TV services + 2 Radio services
– Emergency Warning Tests.

1.4 Start date and duration

– 23 January 2023 – 17 March 2023.

1.5 Location

– Barcelona (Spain)

1.6 Technologies

– 3GPP eMBMS (Release 12) and FeMBMS (Release 14)

1.7 Spectrum and frequencies

– 5 MHz in TV channel 39 (617-622 MHz)

1.8 Equipment and infrastructure

– Emission from a rooftop urban site (total height of 30 meters)
– Satellite reception
– Codec & Packager (Ateme)
– Broadcast Service & Control Centre – BSCC (Rohde & Schwarz)
– 1 KW Transmitter (Rohde & Schwarz)
– UE devices (Qualcomm).

Figure 141 shows the scheme of the trial.

FIGURE 141

LTE-based 5G Broadcast block diagram for MWC2023

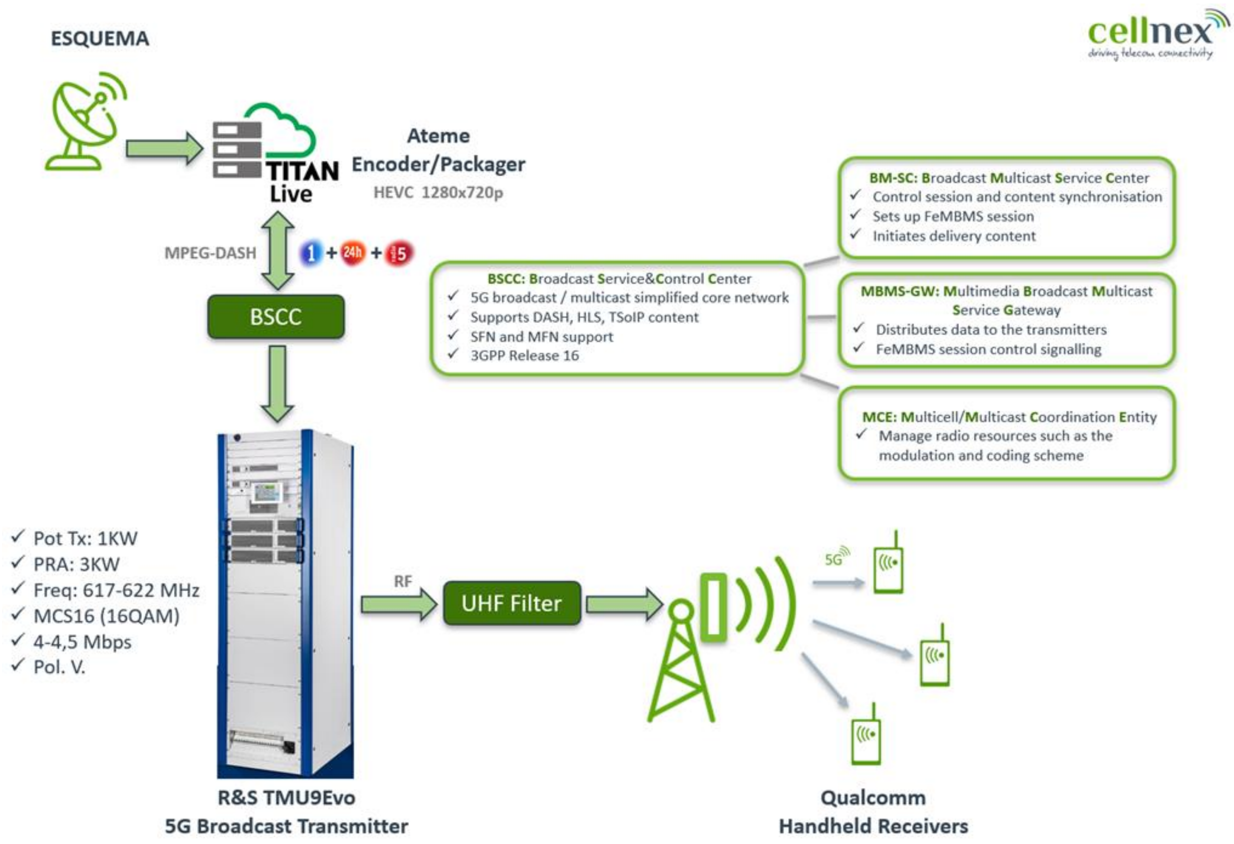


Figure 142 shows the urban site infrastructure, while Fig. 143 is a photograph of the transmission system of the trial.

FIGURE 142

Urban site infrastructure and equipment

FIGURE 143

Transmission system

Figure 144 shows the LTE-based 5G-Broadcast reception Qualcomm device.

FIGURE 144

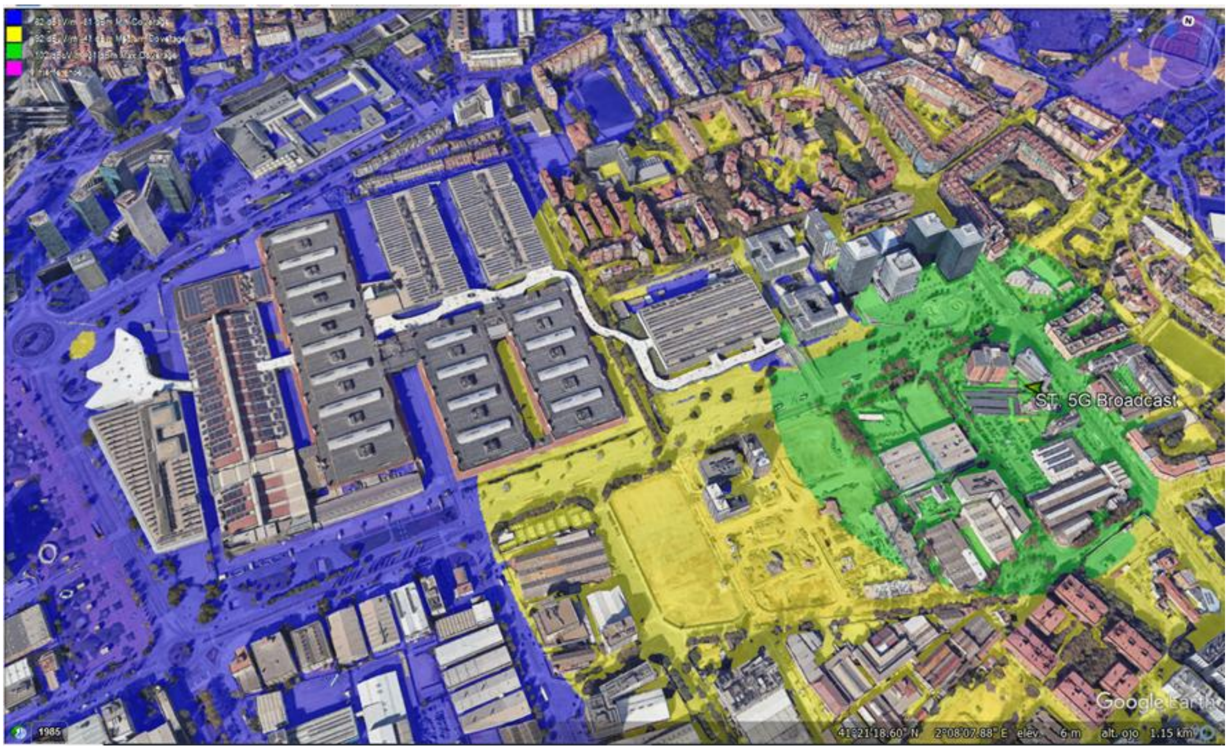
LTE-based 5G Broadcast reception Qualcomm device

Figure 145 shows the result of a simulation with Omni antenna and building only considered for indoor coverage.

Simulated results are OK for outdoor coverage but not yet satisfactory for indoor coverage. Indoor and outdoor measurements confirm this prediction.

FIGURE 145

LTE-based 5G Broadcast simulated results



1.9 Main goals

– Support technology evolution and next-generation connectivity. Show new technologies and opportunities offered by LTE-based 5G Broadcast to view content on the mobile.

– Study elements involved in the whole chain with close cooperation of manufacturers.

– Execution of measurements with different MCS to study the impact in coverage.

1.9.1 Previous trials

Several trials have been carried out in Spain to test and develop the LTE-based 5G broadcast ecosystem. In the following paragraphs some further information is given.

- **Trial 1, MWC20**

During the MWC in 2020 an LTE-based 5G broadcast trial has been carried out using a 50 kW ERP emission with a 1.5 kW Tx power.

The configuration was FeMBMS (Release 14) with MCS27 (64-QAM) and a CP of 200 µs, achieving a bit rate of 15.4 Mbit/s.

The emission was from Collserola tower, the main HPHT in the city of Barcelona covering about 4 M people, using the 750-755 MHz (BW of 5 MHz).

The content included two videos (including HD) and one audio.

The main goals of the trial were: Testing FeMBMS in 700 MHz band in a real environment and testing delivery of TV and radio channel providing information services. Some mobility measures (antenna on a vehicle) and at street level (pedestrian) have been carried out. The main conclusion was that such a high-performance configuration faces challenges for mobility and pedestrian reception.

This has been a result of the joint effort of RTVE, Rohde & Schwarz and Cellnex.

- **Trial 2, during the MWC22**

During the MWC in 2022 a second LTE-based 5G Broadcast trial has been carried out using an indoor 1W ERP emission. It was the first worldwide real demonstration of devices with embedded LTE-based 5G Broadcast chipsets.

The configuration was LTE-based 5G broadcast (Release 16) with MCS23 (64-QAM) and a CP of 66.7 us, achieving a bit rate of ~12 Mbit/s.

The emission was from the Rohde & Schwarz MWC stand using the 617-627 MHz (BW of 10 MHz).

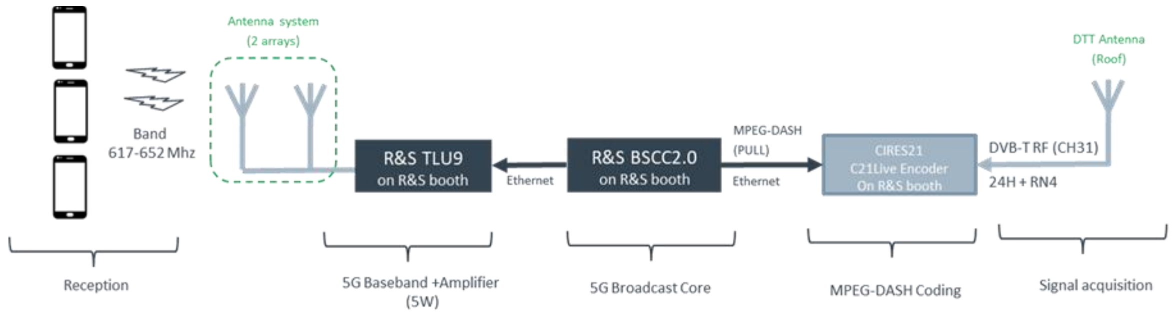
The content included two videos (including HD) and one audio.

The main goal of the trial was to showcase the first Qualcomm mobile devices embedding the LTE-based 5G Broadcast decoder. It was for the very first time that a smartphone formfactor has been utilized in such demonstration without the need of SDR.

This has been a result of the joint effort of RTVE, Rohde & Schwarz, Qualcomm and Cellnex.

FIGURE 146

LTE-based 5G broadcast block diagram for MWC2022



In Fig. 146, content reception includes DTTB signal acquisition on MUX channel 31 in order to obtain RTVE public services RN4 (audio) and 24H (video). This content will be transcoded into HTTP MPEG-DASH multi bitrate protocol through C21Live Encoder and served in PULL mode to BSCC.

BSSC LTE-based 5G Broadcast Core module will consume MPEG-DASH streams previously generated and will create the LTE-based 5G broadcast signal to be delivered to the transmitters. Finally, one low power transmitter (5 W) connected to a two antennas array system will send to mobile receivers LTE-based 5G broadcast signal from BSCC in order to cover R&S and Cellnex Booths on band 617-652 MHz.

Annex 8

France: LTE-based 5G broadcast trial in Paris

1 Summary

During the Roland-Garros tennis tournament in Paris, a LTE-based 5G broadcast trial was deployed using a 1 kW e.r.p. emission. This trial was the result of the efforts of France Televisions, Advalem, Rohde & Schwarz, Qualcomm Technologies and Ateme in collaboration with TDF. TDF deployed a new transmitter at the Eiffel Tower to specifically cover the Roland-Garros stadium and its surroundings, providing both portable and mobile reception to the users; the transmitter was provided by Rohde Schwarz; using Ateme encoding solution; and the receivers used for the demonstration had Qualcomm technology.

During the tennis tournament, the broadcast configuration used eMBMS (Release 12) with MCS14 (16-QAM) achieving 3.7 Mbit/s of capacity, considering the current limitations of receiver performance to 60% of the available raw capacity.

The content included two HD TV services configured for a reception at 720p with AAC audio. The two channels were “France 2 HD” and “France 3 HD”, which were broadcasting the tennis matches on alternating schedules during the tournament.

The main goal of the trial was to showcase how the full value chain works, from taking the signal in a remote location, coding the signal, transporting it to the transmitter for broadcasting from a High Tower site, up to watching the content on a mobile device and comparing latency to the live event and other transmission means (Fixed DTT, IP streaming). This aim of this trial was to demonstrate to a range of stakeholders the abilities of LTE-based 5G Terrestrial broadcast to handle the transmission and good reception of live signals in a public environment.

The experiment was prolonged after the tournament to examine the real performance of two further configurations in portable and mobile environments: MCS17 (64-QAM) with 4.5 Mbit/s capacity and MCS21 (64-QAM) with 6.2 Mbit/s capacity.

2 Participants

– France Televisions – National Public TV Content Provider – EBU member (https://www.francetelevisions.fr/)

TDF – Broadcast Network Operator – BNE and EBU member, (https://www.tdf.fr)

Advalem Technologies – Video streams collection and transmission (https://www.tdf.fr/tnt-radio/advalem/)

– Rohde & Schwarz (https://www.rohde-schwarz.com)

– Ateme (https://www.ateme.com)

– Qualcomm Technologies (https://www.qualcomm.com).

3 Services

– Linear TV services (DASH). Test with 2 TV services

4 Experimentation dates

– 28 May 2023 – 11 June 2023.

5 Location

– Paris (France)

6 Technologies

– 3GPP eMBMS (Release 12) and FeMBMS (Release 14)

7 Spectrum and frequencies

– 5 MHz in TV channel 41 (630-638 MHz) – adjacent to DTT on channel 42

8 Equipment and infrastructure

The experiment was operated from two locations:

– Romainville technical centre

- Programs collection from France Televisions (Advalem)
- Coding and packaging (Ateme)
- Transport to the emission site (TDF)

– Eiffel-Tower

- Emission from a dedicated antenna (290 m high above ground level, 1 kW e.r.p.)
- Broadcast Service & Control Centre – BSCC (Rohde & Schwarz)
- 200 W Transmitter (Rohde & Schwarz)

Figures 147 to 149 show the block diagram of the trial, the Eiffel Tower broadcasting site and the transmission equipment.

FIGURE 147

LTE-based 5G broadcast block diagram for Roland-Garros 2023

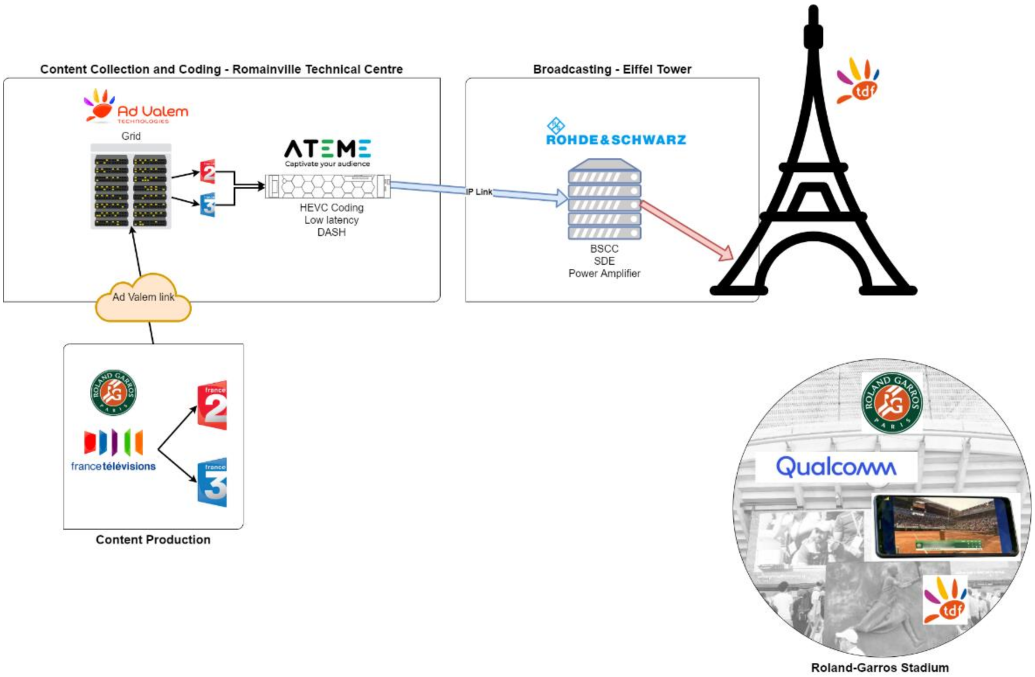


FIGURE 148

Eiffel-Tower broadcasting site

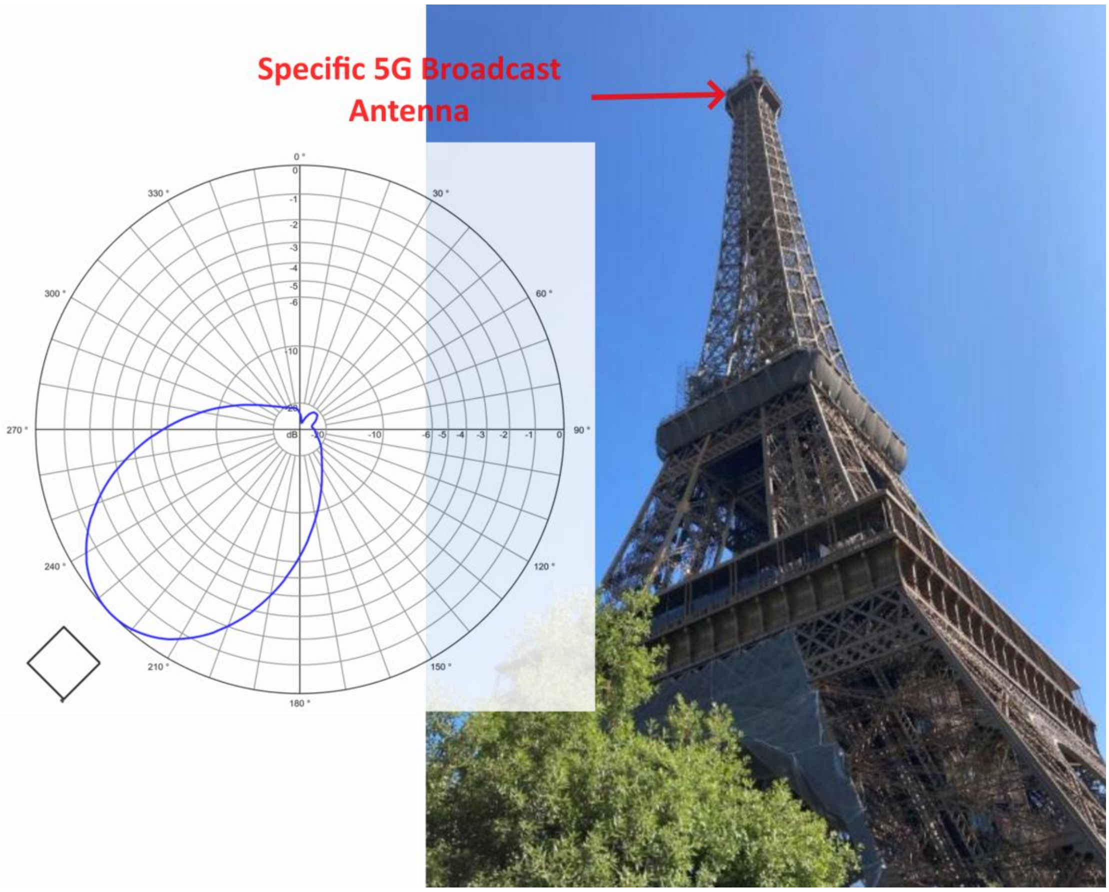


FIGURE 149

Transmission system (including spectrum monitoring and configuration of the BSCC)

UE devices (Qualcomm) were used during the trial, both for pedestrian reception in the stadium during the tennis tournament and for vehicular reception after the tournament, when qualifying in-car reception in the vicinity of Roland-Garros.

FIGURE 150

LTE-based 5G Broadcast reception devices

9 Key findings

– The LTE-based 5G Broadcast system was successfully presented to several stakeholders interested in a possible future service, showcasing the ability to receive the live contents from two programs covering the Roland-Garros event.

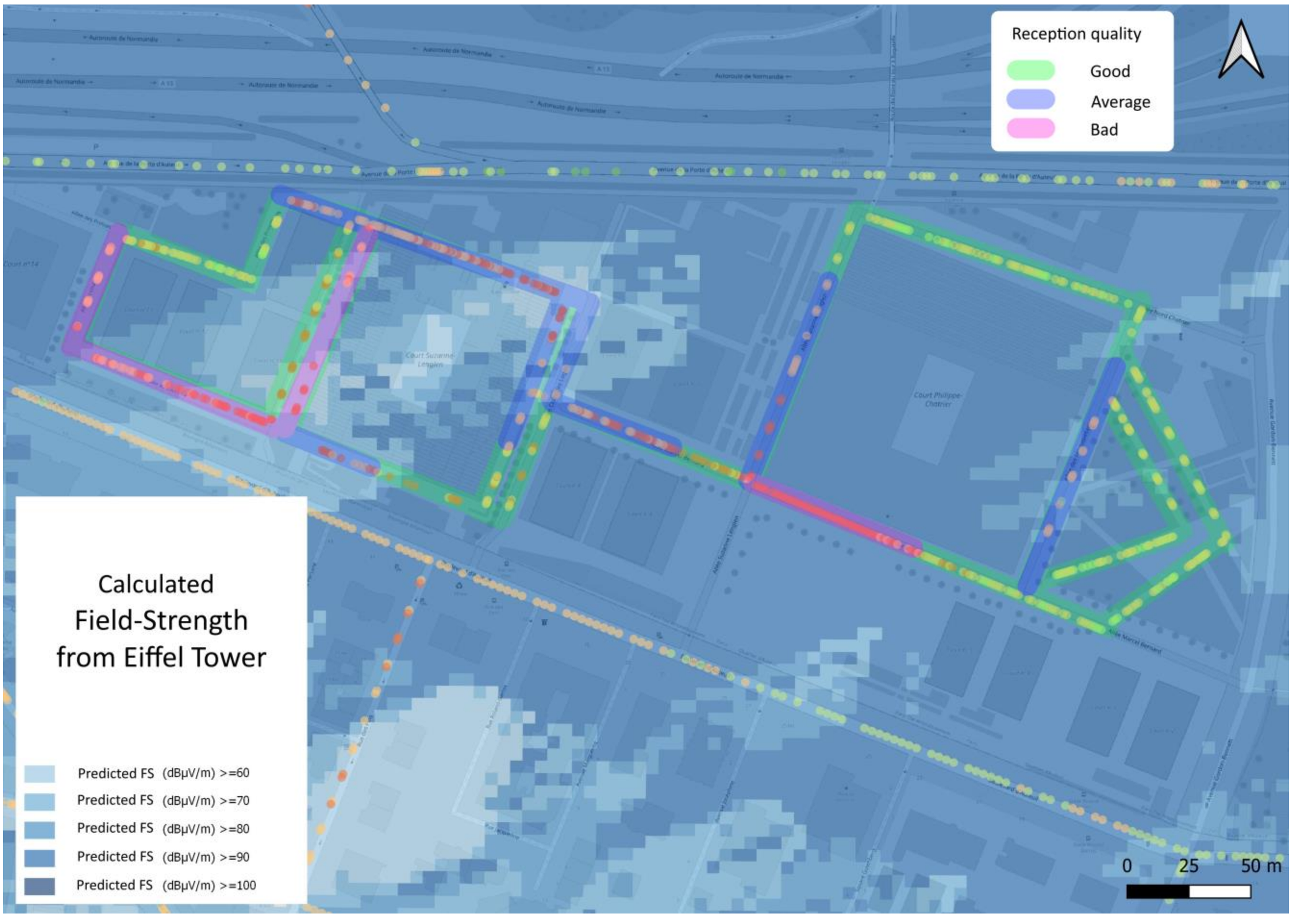
– The observed latency is slightly worse than fixed DTT reception (by 5 to 10 seconds), while being significantly better than that of IP based reception of the same programs (by about 1 minute).

– The trial was the occasion to test various configurations of the transmission parameters:

  • The more robust MCS variant (MCS14) is necessary to achieve a good coverage of the Roland-Garros stadium, yet not a full coverage was reached due to the challenging reception conditions in different places of the stadium, in particular because of the tall concrete structures surrounding the Philippe Chatrier and Suzanne Lenglen courts, as can be seen on Fig. 151. Despite the use of a high resolution 4m DEM, the effect of these structures was not completely visible in the predicted coverage.

FIGURE 151

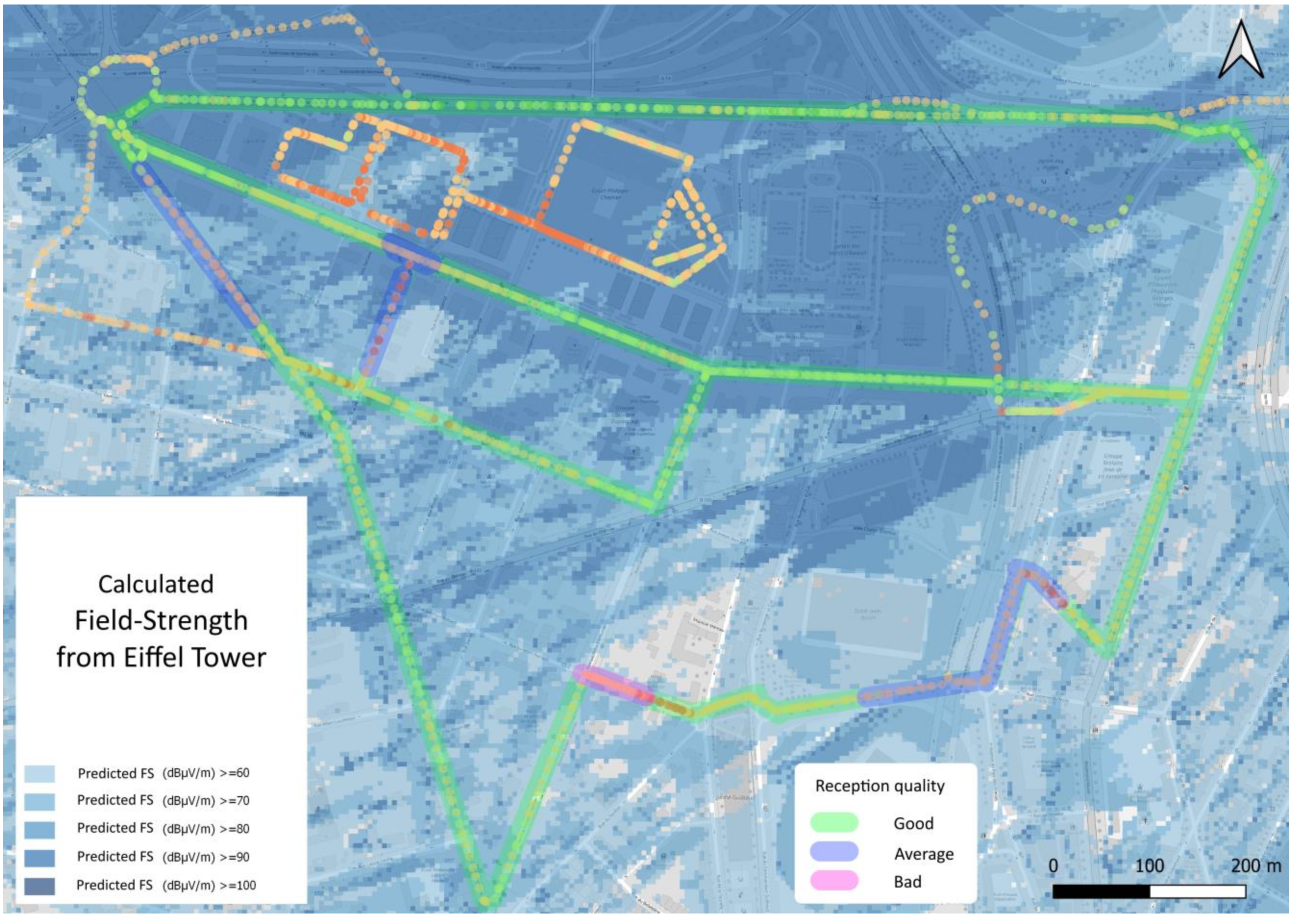
LTE-based 5G Broadcast user perceived reception quality in the Roland-Garros stadium (MCS14)



- This same MCS provides a good vehicular reception quality in the streets close to the Roland-Garros stadium (two configurations were tested: smartphone on the back of the driver's seat and smartphone on the vehicle dashboard). The use of less robust MCS (MCS17 and MCS21) is less favourable mainly at the south of the tested route, where the effects of the limited coverage (due to limited ERP as well as antenna pattern) were quite sensitive. The three MCS configurations were also tested along other driving routes, with similar conclusions.

FIGURE 152

LTE-based 5G Broadcast user perceived reception quality in streets around the Roland-Garros stadium (MCS14)



Annex 9

Field trial of LTE-based 5G Broadcasting System for Mobile Handheld Applications in Korea (Republic of)

1 Overview

In the 3rd Generation Partnership Project (3GPP), the evolved Multimedia Broadcast Multicast Services (eMBMS, called LTE broadcast by 3GPP) was first standardized in Release-9 to provide high-quality live streaming services for a large volume of users simultaneously. After the first standardization of eMBMS, some functional improvements for eMBMS had been made through several releases. Then, the Further Evolved Multimedia Broadcast Multicast Service (FeMBMS) was endorsed in Release-14, reflecting requests from broadcasters that a sizeable inter-site distance (ISD) be supported for single frequency network (SFN) operation. In 2019, the work item for improving the utilization of FeMBMS was finished in Release-16. Since FeMBMS satisfies the requirements for a branch of 5G technology, it is being called "LTE-based 5G terrestrial broadcast system" by

ETSI. After that, 3GPP added 6/7/8 MHz as the transmission bandwidth of LTE-based 5G terrestrial broadcast in Release-17. In this text we will refer to this as “5G Broadcast”.[10]

5G Broadcast is regarded as a highly-developed system supporting terrestrial broadcasting services for mobile handheld receivers. In line with the expected expansion of mobile broadcasting services worldwide, a comprehensive performance evaluation result is provided here. First, the physical layer performance is analysed, considering the realistic channel environments of model terrestrial broadcasting infrastructures. Next, the complexity of the system required to support broadcasting services in the mobile handheld environment is evaluated through network simulations. To verify the performance evaluation results from the computer/network simulations, lab testing and field testing were carried out based on the FPGA-implemented hardware.

2 Physical layer discussion

Table 40 summarizes the physical layer parameters of 5G Broadcast, assuming 8 MHz bandwidth. In 3GPP, using a subcarrier spacing (SCS) of 1.25 kHz is primarily considered for High-Power/High-Tower (HPHT) infrastructure in FeMBMS. However, the value of Cyclic Prefix (CP) length is fixed for each parameter combination in 5G Broadcast.

TABLE 40

PHY parameters of 5G Broadcast (8MHz BW)

Standard	Physical Channel	Useful BW (MHz)	FFT Size	Sub-carrier Spacing (kHz)	Sampling Rate (MHz)	OFDM Symbol Duration (us)	MAX. CP Duration (us)
5G Broadcast	PBCH	1.08	512	15.0	7.68	66.7	16.7
	PDCCH/ PDSCH	4.5					
	PMCH	7.2	6144	2.50	15.36	400	100
			12288	1.25		800	200
			41472	0.37		2700	300

3 Computer simulation results

Extensive link-level simulations were performed to evaluate the physical layer characteristics of 5G Broadcast for mobile environments. Hence, the simulation considers a single stream passed through a single transmission antenna over various channel environments derived from channel modelling. The remaining considerations are summarized in Table 41.

[10] Release 17 is referenced in ETSI TS 103 720, which is entitled “5G Broadcast System for linear TV and radio services; LTE-based 5G terrestrial broadcast system.”

TABLE 41

Evaluation conditions

Centre frequency	500 MHz
Bandwidth	8 MHz
Channel Model	India-Urban, India-Rural
UE Mobility	3 km/h, 40 km/h, 120 km/h
Number of Tx Antenna	1
Channel Estimation	1) Ideal (All tones without noise are used.) 2) Low-complexity linear (LS estimation with linear interpolation is used.)

TABLE 42

LPLT SFN channel profile: Urban case in Bengaluru (India-Urban)

Station ID	Rel. Delay [us]	Type	Rel. Power [dB]	Phase Shift [rad] (Stationary)	Doppler Spectrum (Mobile)
U1	−2.1	NLoS	−1.9	4.8551	Classical
U2	−0.8	NLoS	−12.0	3.7580	Classical
U0	0.0	NLoS	0.0	0.0000	Classical
U3	0.5	NLoS	−6.4	3.4191	Classical
U4	1.3	NLoS	−12.5	5.4302	Classical
U5	1.9	NLoS	−21.7	0.1546	Classical
U6	4.1	NLoS	−11.5	2.2159	Classical
U7	4.6	NLoS	−9.7	5.8645	Classical
U8	8.2	NLoS	−22.2	3.0530	Classical
U9	9.4	NLoS	−24.6	0.6286	Classical
U10	9.9	NLoS	−17.2	1.0936	Classical
U11	11.9	NLoS	−28.5	3.4630	Classical
U12	11.9	NLoS	−29.1	3.6648	Classical
U13	12.0	NLoS	−29.4	2.8338	Classical
U14	14.8	NLoS	−30.6	3.3343	Classical
U15	16.6	NLoS	−21.7	5.9284	Classical
U16	18.3	NLoS	−27.4	1.0995	Classical
U17	21.2	NLoS	−14.7	3.9521	Classical
U18	23.5	NLoS	−24.9	2.1285	Classical
U19	26.5	NLoS	−19.8	5.7752	Classical

TABLE 43

LPLT SFN channel profile: Rural case in Bengaluru (India-Rural)

Station ID	Rel. delay (us)	Type	Rel. power (dB)	Phase Shift [rad] (Stationary)	Doppler Spectrum (Mobile)
R1	**−6.8**	**LoS**	**−0.6**	**2.1388**	**−0.7193fd shift**
R0	0.0	LoS	0.0	0.0000	0.9528fd shift
R2	9.6	LoS	−6.2	1.6336	0.9371fd shift
R3	21.8	LoS	−15.3	5.6888	0.7615fd shift
R4	37.7	NLoS	−28.0	4.8551	Classical
R5	46.4	NLoS	−27.6	3.7580	Classical
R6	52.6	NLoS	−26.6	3.4191	Classical
R7	53.8	NLoS	−28.5	5.4302	Classical
R8	54.2	NLoS	−27.9	0.1546	Classical
R9	59.6	NLoS	−27.2	2.2159	Classical
R10	60.3	NLoS	−18.7	5.8645	Classical
R11	60.7	NLoS	−23.1	3.0530	Classical
R12	61.9	NLoS	−27.7	0.6286	Classical
R13	62.6	NLoS	−19.2	1.0936	Classical
R14	66.6	NLoS	−24.5	3.4630	Classical
R15	66.8	NLoS	−22.9	3.6648	Classical
R16	67.4	NLoS	−26.6	2.8338	Classical
R17	97.9	NLoS	−28.0	3.3343	Classical

Since various receiver implementations are possible, two channel-estimation rules – ideal and low-complexity linear estimation – are used for computer simulations. When ideal estimation is employed, channel values are purely obtained from pilot symbols assumed to be allocated to all subcarriers and received without noise. This means that the block error rate (BLER) performance with ideal estimation corresponds to the upper bound that could be obtained in a real field. On the other hand, linear interpolation is employed using a low-complexity channel estimation method, and when used, channel values are obtained by frequency-domain linear interpolation after least square (LS) estimation on the pilot symbols.

The BLER performance of data channels is evaluated depending on whether a line of sight (LoS) or a near-line of sight (NLoS) path is present. Note that India-Urban and India-Rural channels are used for LoS and NLoS environments, respectively, whose channel profiles are given in Table 42 and Table 43, which have been obtained from measured data on wireless channel environments in Bengaluru, India. Their maximum delay spreads are about 30 µs and 100 µs, respectively.

The performance of the data channels of 5G Broadcast is evaluated when the target data rate is 5 Mbit/s, 10 Mbit/s, and 15 Mbit/s, corresponding to different service (*Svc*) classes, whose configurations are given in Table 28. Different MCS indices are applied to the different target data rates in 5G broadcast. In Table 28, the required CNR to achieve BLER = 10^{-4} over an AWGN channel is included as a baseline performance at each service class for 5G broadcast. The BLER performance of the 5G Broadcast PMCH over an India-Urban channel (NLoS channel) and an India-Rural channel (LoS channel) are evaluated in Fig. 153.

The results show that the required CNR varies according to the target data rate, mobility, and channel estimation.

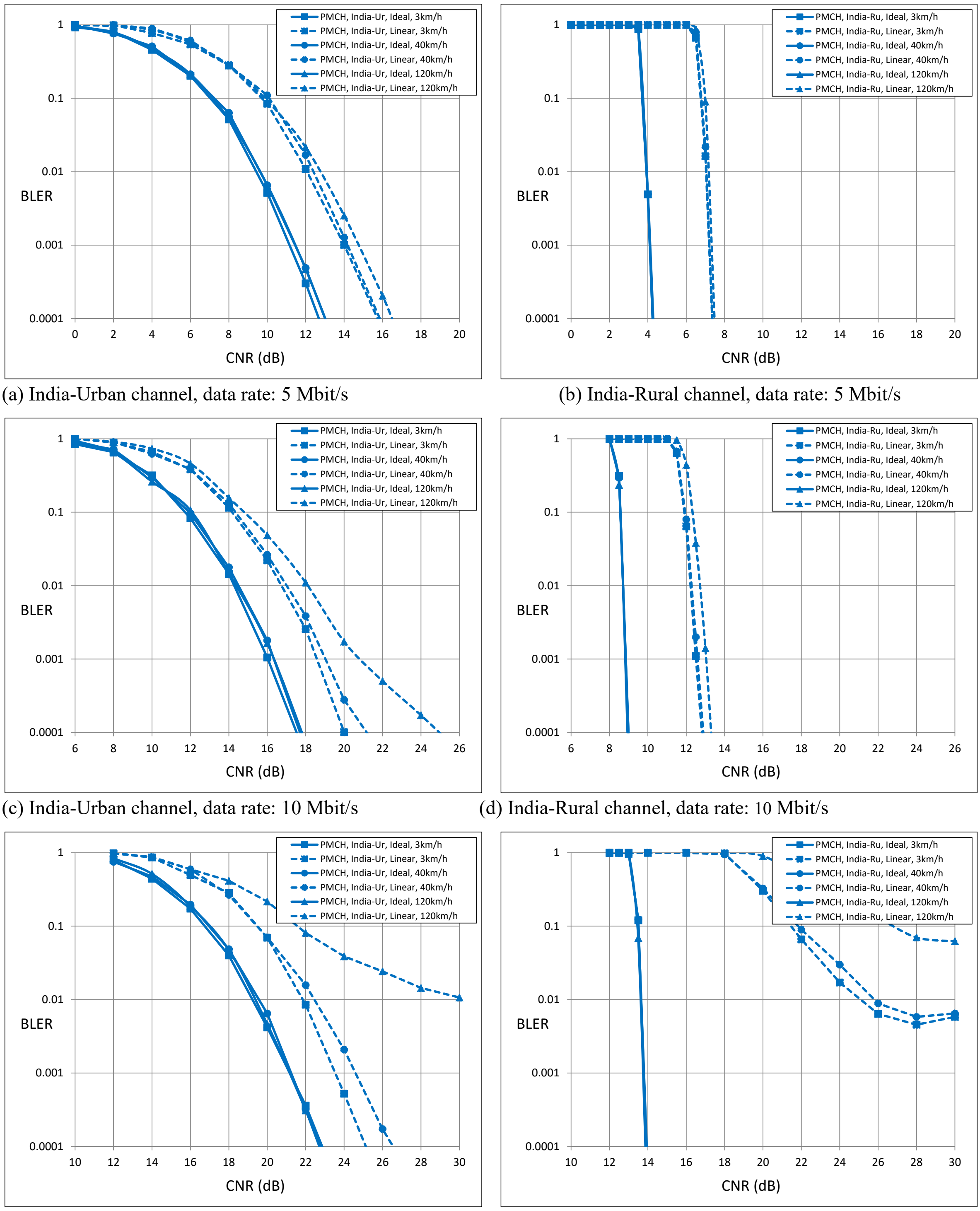
TABLE 44

Configuration for data channels (8 MHz BW)

		Svc1	***Svc2***	***Svc3***
5G Broadcast	MCS index	8	14	20
	TBS	5544	10296	15840
	Code rate	0.58	0.54	0.553
	Constellation	QPSK	16-QAM	64-QAM
	Data rate (Mbit/s)	5.41	10.04	15.44
	Required CNR (AWGN) (dB)	2.3	7.3	12.1

FIGURE 153

Performance of the 5G Broadcast PMCH over India-Urban and India-Rural channels



(a) India-Urban channel, data rate: 5 Mbit/s

(b) India-Rural channel, data rate: 5 Mbit/s

(c) India-Urban channel, data rate: 10 Mbit/s

(d) India-Rural channel, data rate: 10 Mbit/s

(e) India-Urban channel, data rate: 15 Mbit/s

(f) India-Rural channel, data rate: 15 Mbit/s

4 Network complexity evaluation

Broadcast operators recognize spectral efficiency as an essential factor in network design. The reason is that the complexity of the network depends on the trade-off between throughput and service reliability. Specifically, the network complexity is a function of the number and size of towers used in the network. Given the necessary infrastructure (tower deployment) to reach the service target, one can evaluate the site logistics, transmission power requirement, and the backbone connectivity required for maintaining single frequency network (SFN) synchronization. Even if the SFN operator can reuse existing infrastructure, the number of operational towers and physical layer efficiency dominate the infrastructure required for each protocol standard. Given the target service area and QoS, the protocol efficiency can be directly translated into the network complexity.

As a practical example, a study was made in the urban metropolis of Bengaluru, India. The Bengaluru plateau is notable for this comparison because of the relatively flat terrain where transmissions need to rely on a low-power/low-tower (LPLT) infrastructure. This work is based on handheld use cases in LPLT SFN environments. The analysis uses data from the existing telecom stations, clutter (terrain type data), and population data; thereby conforming with an actual deployment. Using this input data, the number of SFN transmitters (NoST) required to ensure a 95% reception probability in the target area of interest (AoI) is evaluated for 5G Broadcast. The simulations use data from existing mobile telecom sites in Bengaluru, where a total of 1 576 sites are available within the AoI. The parameters for the test scenario are shown in Table 45.

The simulation results in Fig. 154 show the number of sites needed for network feasibility. Given the site location data, an optimal subset of those tower sites is determined to fulfil the QoS across the AoI with minimal overlap. According to the results for *Svc1*, 5G Broadcast requires 345 SFN transmitters to be operated. Likewise, 590 sites are needed for 10 Mbit/s service (*Svc2*).

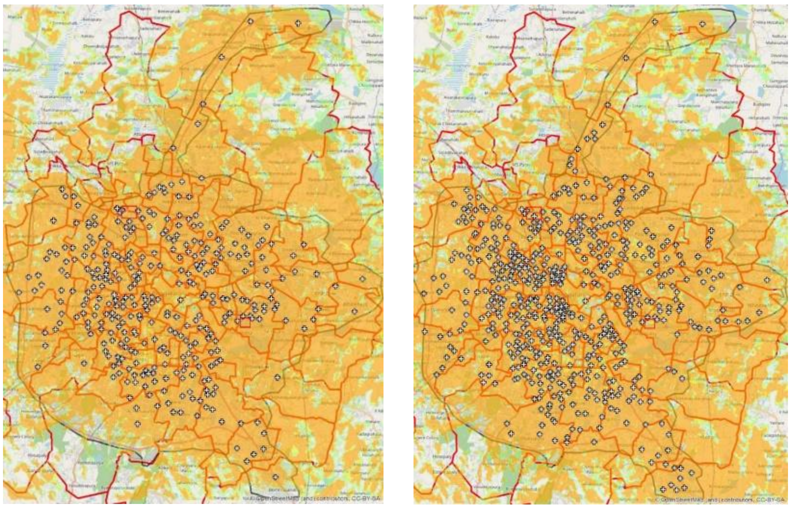
TABLE 45

Scenario description

Centre frequency	500 MHz
Transmit power	40 W (46 dBm)
Antenna height	14-100 m (avg. 32 m)
Antenna type	Omni-directional
Antenna gain	9 dBi
EIRP	55 dBm
Reception mode	Handheld Indoor (3 km/h)
Network type	LPLT
Antenna type	Omni-directional, Colinear antennas, Vertically polarized
Antenna gain	−9.5 dBi
Noise figure	7.5 dB
Outdoor signal Std. dev. (Log-normal)	5.5 dB (Rec. ITU-R P.1546-6)
Coverage target	95%

FIGURE 154

Required tower deployment for 5G Broadcast: (a) *Svc1* (345 sites), (b) *Svc2* (590 sites)



(a) (b)

5 Laboratory test results

For the laboratory test, a 3GPP Rel-17 5G Broadcast compliant exciter and receiver were used. The transmission parameters for the laboratory test are summarized in Table 46. The broadcasting bandwidth in use in South Korea, 6 MHz, and the centre frequency of 768 MHz, the experimental station frequency available in South Korea, were considered. For the mobile broadcasting environment, 8K FFT size and related transmission parameters were considered. TU-6 channel and India-Urban channel were considered as the receiving channel environment, and laboratory tests were performed considering receiver movement speeds of 3 km/h, 40 km/h, and 120 km/h in both channels, respectively.

TABLE 46

Laboratory physical layer description

PHY transmission parameters for 5G Broadcast	
Centre frequency	768 MHz
Bandwidth	6 MHz (Occupied bandwidth = 5.4 MHz)
FFT Size	12288
Guard interval	200 µs
Subcarrier spacing	1.25 kHz
Pilot pattern	SP3_2

TABLE 47

Laboratory evaluation assumptions

Reception conditions for 5G Broadcast	
Channel model	TU-6, India-Urban
UE mobility	3 km/h, 40 km/h, 120 km/h
Number of Tx antenna	1
Channel estimation	DFT-based

In this laboratory test, four target data rates of 2.5 Mbit/s, 5 Mbit/s, 10 Mbit/s and 15 Mbit/s were considered for each service class, whose configurations are described in Table 48. As initial performance results from laboratory tests, the SNR values required to achieve BLER = 10^{-4} over an AWGN channel are presented as the baseline performance for each service class. The performance measurement results in terms of BLER of the PMCH corresponding to the data payload are presented in Fig. 155. Note that only PMCH performance excluding PBCH and PDCCH/PDSCH parts was measured in the laboratory test.

The measurement results show that the required SNR strongly depends on the target data rate and mobility. In general, performance deteriorates as the moving speed of the receiver increases, and this shows a similar trend in both TU-6 and India-Urban channels. In the case of 2.5 Mbit/s, similar performance was observed at all measured speeds, and in the case of 5 Mbit/s, a performance deterioration of approximately 2 dB was observed when the speed increased to 120 km/h. In the case of 10 Mbit/s, decoding was not possible for a speed of 120 km/h. In the case of 15 Mbit/s, it was observed that BLER = 10^{-4} could not be reached for all speeds.

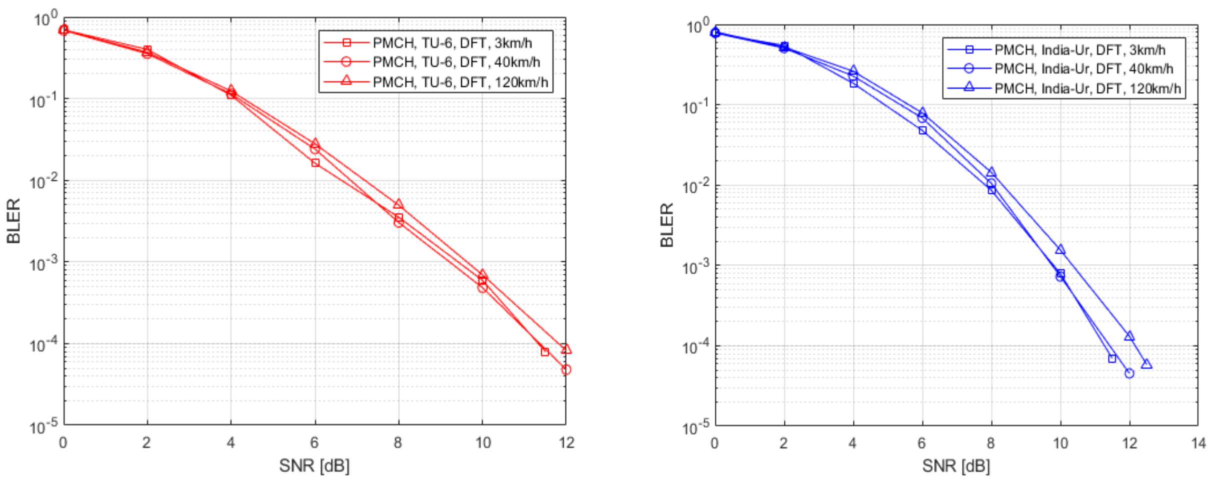
TABLE 48

Laboratory configuration for data channels corresponding to service classes (6 MHz BW)

		Svc0	**Svc1**	**Svc2**	**Svc3**
5G Broadcast	MCS index	5/15	5/15	7/15	10/15
	TBS	QPSK	16-NUC	64-NUC	64-NUC
	Code rate	0.373	0.737	0.498	0.764
	Constellation	QPSK	16-QAM	64-QAM	64-QAM
	Data rate (Mbit/s)	2.60	5.22	10.41	16.00
	Required SNR measured through laboratory test (AWGN) (dB)	−0.4	4.3	10.9	16.6

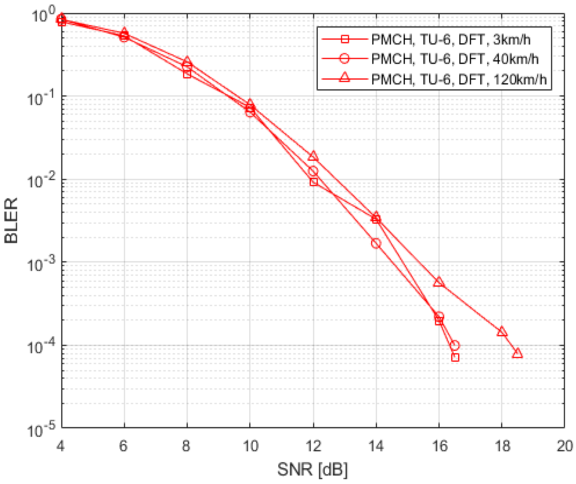
FIGURE 155

Performance of the 5G Broadcast PMCH over TU-6 and India-Urban channels

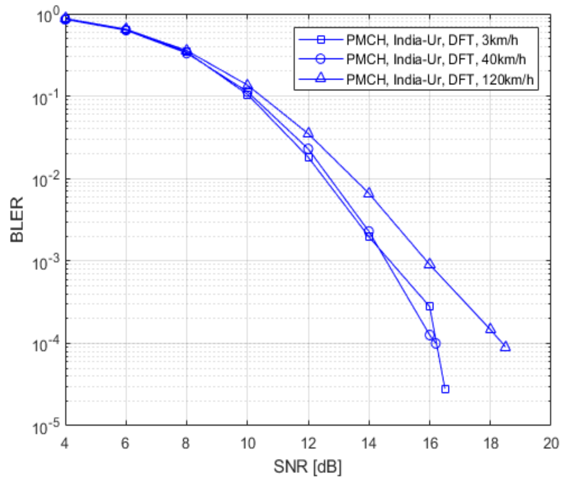


(a) TU-6 channel, data rate: 2.5 Mbit/s

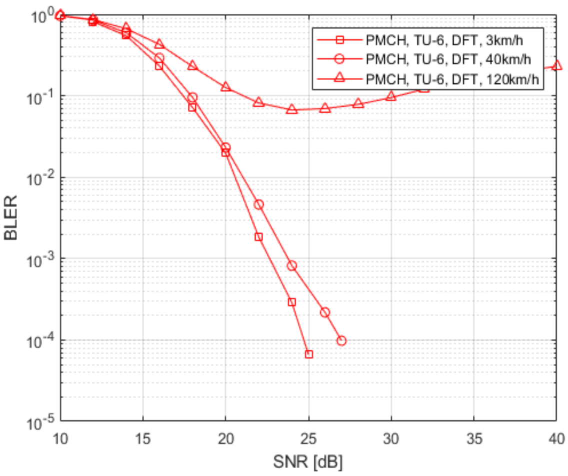
(b) India-Urban channel, data rate: 2.5 Mbit/s



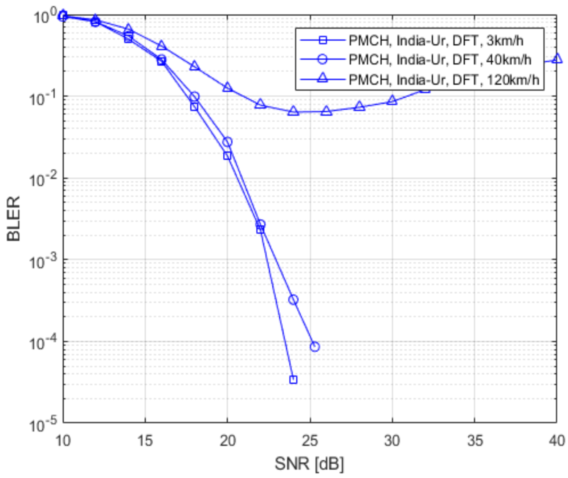
(c) TU-6 channel, data rate: 5 Mbit/s



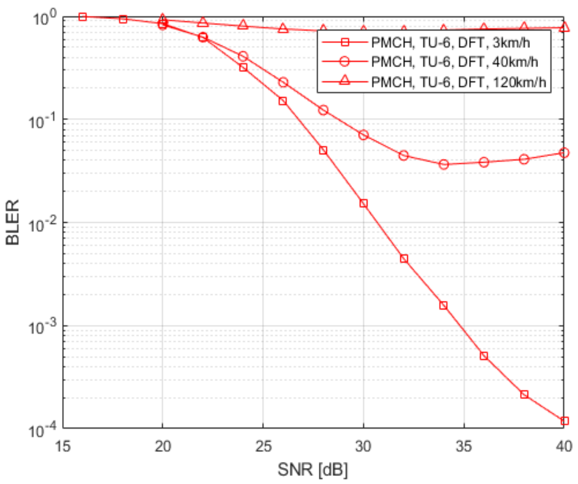
(d) India-Urban channel, data rate: 5 Mbit/s



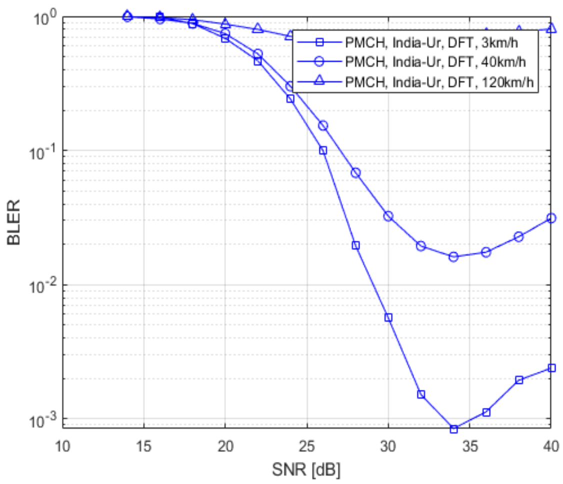
(e) TU-6 channel, data rate: 10 Mbit/s



(f) India-Urban channel, data rate: 10 Mbit/s



(g) TU-6 channel, data rate: 15 Mbit/s



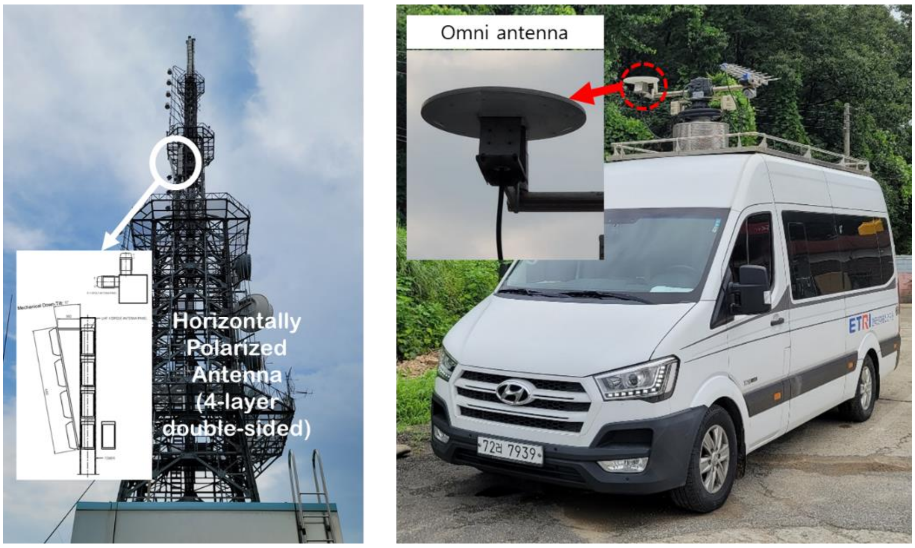
(h) India-Urban channel, data rate: 15 Mbit/s

6 Field test results

The field test used the same 5G Broadcast hardware systems as in the laboratory test, as well as the transmission parameters in Table 46. The field test was conducted in the north Gyeonggi-do area of South Korea. For the transmission, a 4-layer double-sided horizontally-polarized antenna was used. The transmission power was set to 100 watts. For the signal reception and mobile measurement, a test vehicle equipped with a disk-shaped omni-directional antenna was used as shown in Fig. 156(b). Note that in the laboratory test, only the PMCH performance corresponding to the data payload was observed, but in the field test, the overall performance of the physical layer including PBCH and PDCCH/PDSCH was measured.

FIGURE 156

Transmission and reception facilities



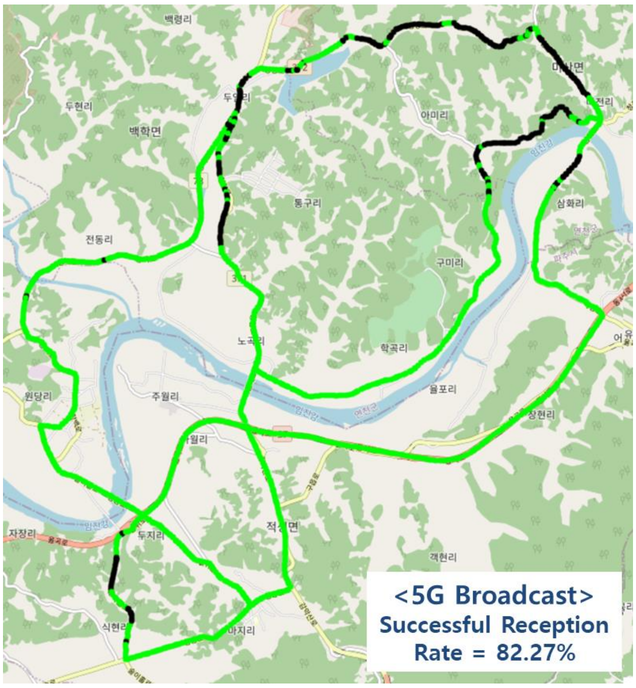
(a) Transmit antenna (b) Test vehicle and receive antenna

Figure 157 shows the signal receivability recorded throughout the test route. Whenever the signal decoding failed, the corresponding spot was marked in black, whereas the green dots indicate that the received signal was successfully decoded during the corresponding unit record duration. Each dot is a result saved every second, and was recorded only when the vehicle was moving to prevent duplicate data from being recorded through measurements. The transmitting station is located at the southeast area of the test route, and as there is a low mountainous area to the north, it is not easy to secure LOS in that area, so the received field strength is quite low. For this reason, as the target data rate increases, the area where reception fails gradually expands in the northern section. Moreover, in the case of 10 Mbit/s and 15 Mbit/s, reception failures occurred frequently even in open areas rather than mountainous areas, and it was observed that reception failures were widely distributed throughout the test route. As a result, the reception success rate was found to drop significantly from 82% at 2.5 Mbit/s to 30% at 15 Mbit/s.

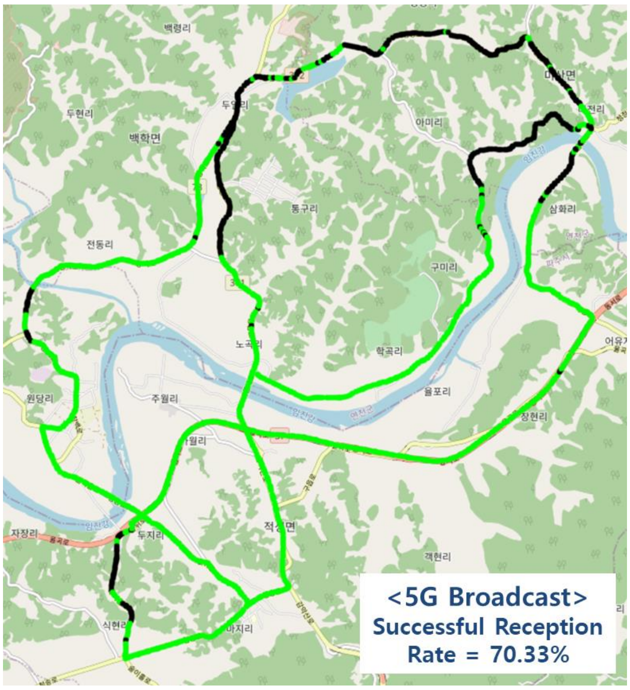
Figure 158 illustrates the successful reception rate with respect to received field strength, which equivalently indicates the erroneous second rate (ESR) metric. As shown in Fig. 158, 2.5 Mbit/s, 5 Mbit/s, and 10 Mbit/s required −80.3 dBm, −75.5 dBm, and −49.9 dBm of field strength to ensure successful reception rate of 95%, respectively. However, in the case of 15 Mbit/s, a successful reception rate of 95% could not be guaranteed at any received field strength.

FIGURE 157

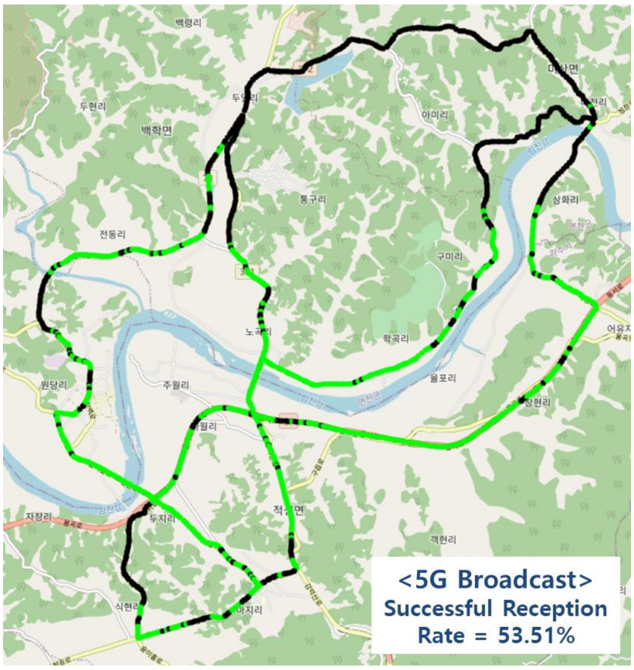
Signal receivability corresponding to each target data rate



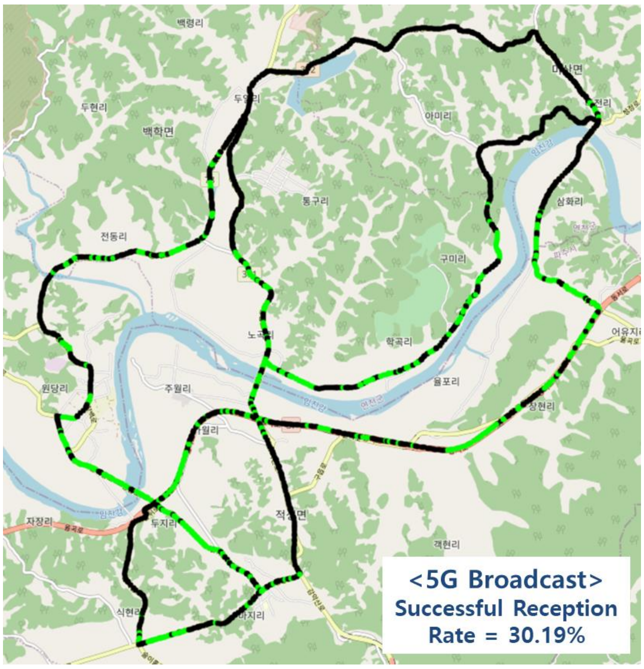
(a) 2.5 Mbit/s



(b) 5 Mbit/s



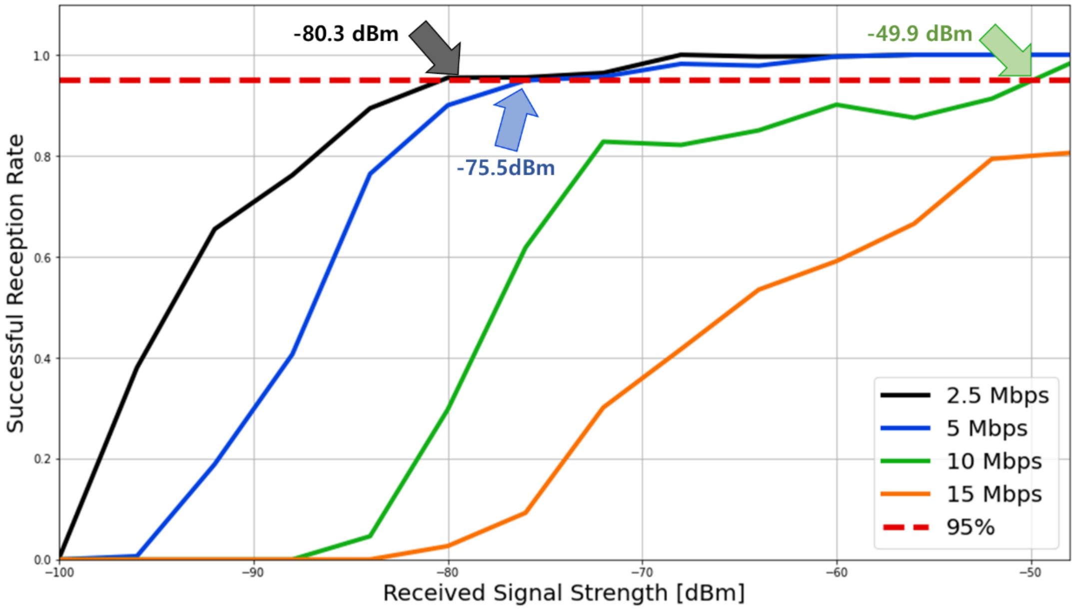
(c) 10 Mbit/s



(d) 15 Mbit/s

FIGURE 158

Mobile reception reliability for various target data rate



7 Summary

This study verifies the performance of 5G Broadcast physical layer under mobile reception condition. The data represents comprehensive performance evaluation results from computer simulation, laboratory test, and field test. Various target data rate scenarios were considered, and the evaluation was conducted assuming a realistic transmission and reception environment. Network complexity of the required broadcasting systems is also presented.

Annex 10

Field trial of ATSC 3.0 system for mobile handheld applications in Korea (Republic of)

1 Overview

In 2016, the Advanced Television Systems Committee (ATSC) approved the physical layer standard for the next generation digital terrestrial television broadcasting (DTTB) system ATSC 3.0. It mainly focuses on supporting the efficient delivery of high-quality broadcasting services such as ultra-high definition (UHD) TV for both fixed and mobile receivers. For this reason, ATSC optimized the physical (PHY) layer of ATSC 3.0 in terms of spectral efficiency, reception robustness, and transmission flexibility. Since ATSC 3.0 endorsed various innovative technologies such as layered division multiplexing (LDM), low-density parity-check (LDPC) codes, non-uniform constellation (NUC), and optimal time interleaver, its physical layer is regarded as the most advanced wireless transmission system.

ATSC 3.0 is regarded as a highly-developed system supporting terrestrial broadcasting services for mobile handheld receivers. In line with the expected expansion of mobile broadcasting services worldwide, a comprehensive performance evaluation result is provided here. First, the physical layer performance is analysed, considering the realistic channel environments of model terrestrial broadcasting infrastructures. After that, the system complexity required to support broadcasting services in the mobile handheld environment is evaluated through network simulations. To verify the performance evaluation results from the computer/network simulations, laboratory test and field test are carried out based on the FPGA-implemented hardware.

2 Physical layer discussion

Since ATSC 3.0 was developed to support wide coverage based on a High-Power/High-Tower (HPHT) infrastructure, it uses a smaller subcarrier spacing (SCS) compared with many wireless communication standards. In ATSC 3.0, either 8K, 16K, or 32K is used as FFT size, depending on the service scenario. For fixed rooftop reception, 16K or 32K FFT is recommended, whereas 8K FFT is used primarily for mobile broadcasting. The minimum SCS for 6/7/8 MHz channels are 0.211, 0.246, and 0.281 kHz, respectively. In terms of pilot pattern and Cyclic Prefix (CP) length, several options are available for each bandwidth in ATSC 3.0. Table 49 summarizes the physical layer parameters of ATSC 3.0, assuming 8 MHz bandwidth. As shown in Table 49, ATSC 3.0 with an 8K FFT is considered in this performance evaluation for terrestrial broadcasting services.

TABLE 49

PHY parameters of ATSC 3.0 (8 MHz BW)

Standard	Physical channel	Useful BW (MHz)	FFT Size	Sub-carrier spacing (kHz)	Sampling rate (MHz)	OFDM symbol duration (µs)	MAX. CP duration (µs)
ATSC 3.0	Bootstrap	4.5	2 048	3.0	6.144	333	166.7
	Preamble/ Subframe	7.344 (7.776)[11] /7.776	8 192	1.125	9.216	889	222.2
			16 384	0.562		1 777	444.4
			32 786	0.281		3 555	527.8

3 Computer simulation results

Extensive link-level simulations were performed to evaluate the physical layer capability of ATSC 3.0 for mobile environments. Hence, the simulation considers a single stream passed through a single transmission antenna over various channel environments derived from channel modelling. The remaining considerations are summarized in Table 50.

[11] 1st preamble symbol has 7.344 MHz bandwidth, and other preamble symbols have 7.776 MHz bandwidth.

TABLE 50

Evaluation conditions

Centre frequency	500 MHz
Bandwidth	8 MHz
Channel model	India-Urban, India-Rural
UE mobility	3 km/h, 40 km/h, 120 km/h
Number of Tx antenna	1
Channel estimation	1) Ideal (All tones without noise are used.) 2) Low-complexity linear (LS estimation with linear interpolation is used.)

TABLE 51

LPLT SFN channel profile: Urban case in Bengaluru (India-Urban)

Station ID	Rel. delay (us)	Type	Rel. power (dB)	Phase shift (rad) (stationary)	Doppler spectrum (mobile)
U1	−2.1	NLoS	−1.9	4.8551	Classical
U2	−0.8	NLoS	−12.0	3.7580	Classical
U0	0.0	NLoS	0.0	0.0000	Classical
U3	0.5	NLoS	−6.4	3.4191	Classical
U4	1.3	NLoS	−12.5	5.4302	Classical
U5	1.9	NLoS	−21.7	0.1546	Classical
U6	4.1	NLoS	−11.5	2.2159	Classical
U7	4.6	NLoS	−9.7	5.8645	Classical
U8	8.2	NLoS	−22.2	3.0530	Classical
U9	9.4	NLoS	−24.6	0.6286	Classical
U10	9.9	NLoS	−17.2	1.0936	Classical
U11	11.9	NLoS	−28.5	3.4630	Classical
U12	11.9	NLoS	−29.1	3.6648	Classical
U13	12.0	NLoS	−29.4	2.8338	Classical
U14	14.8	NLoS	−30.6	3.3343	Classical
U15	16.6	NLoS	−21.7	5.9284	Classical
U16	18.3	NLoS	−27.4	1.0995	Classical
U17	21.2	NLoS	−14.7	3.9521	Classical
U18	23.5	NLoS	−24.9	2.1285	Classical
U19	26.5	NLoS	−19.8	5.7752	Classical

TABLE 52

LPLT SFN channel profile: Rural case in Bengaluru (India-Rural)

Station ID	Rel. delay (µs)	Type	Rel. power (dB)	Phase shift (rad) (stationary)	Doppler spectrum (mobile)
R1	−6.8	LoS	−0.6	2.1388	−0.7193fd shift
R0	0.0	LoS	0.0	0.0000	0.9528fd shift
R2	9.6	LoS	−6.2	1.6336	0.9371fd shift
R3	21.8	LoS	−15.3	5.6888	0.7615fd shift
R4	37.7	NLoS	−28.0	4.8551	Classical
R5	46.4	NLoS	−27.6	3.7580	Classical
R6	52.6	NLoS	−26.6	3.4191	Classical
R7	53.8	NLoS	−28.5	5.4302	Classical
R8	54.2	NLoS	−27.9	0.1546	Classical
R9	59.6	NLoS	−27.2	2.2159	Classical
R10	60.3	NLoS	−18.7	5.8645	Classical
R11	60.7	NLoS	−23.1	3.0530	Classical
R12	61.9	NLoS	−27.7	0.6286	Classical
R13	62.6	NLoS	−19.2	1.0936	Classical
R14	66.6	NLoS	−24.5	3.4630	Classical
R15	66.8	NLoS	−22.9	3.6648	Classical
R16	67.4	NLoS	−26.6	2.8338	Classical
R17	97.9	NLoS	−28.0	3.3343	Classical

Since various receiver implementations are possible, two channel-estimation rules (ideal and low-complexity linear estimation) are used for computer simulations. When ideal estimation is employed, channel values are purely obtained from pilot symbols assumed to be allocated to all subcarriers and received without noise. This means that the block error rate (BLER) performance with ideal estimation corresponds to the upper bound that could be obtained in a real field. On the other hand, linear interpolation is employed using a low-complexity channel estimation method, and when used, channel values are obtained by frequency-domain linear interpolation after least square (LS) estimation on the pilot symbols.

The BLER performance of data channels is evaluated depending on whether a line of sight (LoS) or a near-line of sight (NLoS) path is present. Note that India-Urban and India-Rural channels are used for LoS and NLoS environments, respectively, whose channel profiles are given in Table 51 and Table 52, which have been obtained from measured data on wireless channel environments in Bengaluru, India. Their maximum delay spreads are about 30 µs and 100 µs, respectively.

The performance of the data channels of ATSC 3.0 is evaluated when the target data rate is 5 Mbit/s, 10 Mbit/s and 15 Mbit/s, corresponding to different service (*Svc*) classes, whose configurations are given in Table 53. Different modulation orders are applied to the different target data rates in ATSC 3.0. In Table 53, the required CNR to achieve BLER = 10^{-4} over an AWGN channel is included as a baseline performance at each service class for ATSC 3.0. The BLER performance of the ATSC 3.0 subframe over an India-Urban channel (NLoS channel) and an India-Rural channel (LoS channel) are evaluated in Fig. 159.

The results show that the required CNR varies according to the target data rate, mobility, and channel estimation. In particular, the time diversity gain due to time interleaver varies according to the velocity of user equipment (UE), resulting that the slope of BLER curves becomes steeper as the UE velocity increases. When comparing India-Urban channel with India-Rural channel, the slope of the BLER curves over an India-Rural channel is considerably steeper than that of an India-Urban channel, because LoS components reduce the occurrence of deep fading. As a result, time interleaver does not yield significant performance gains in the India-Rural channel.

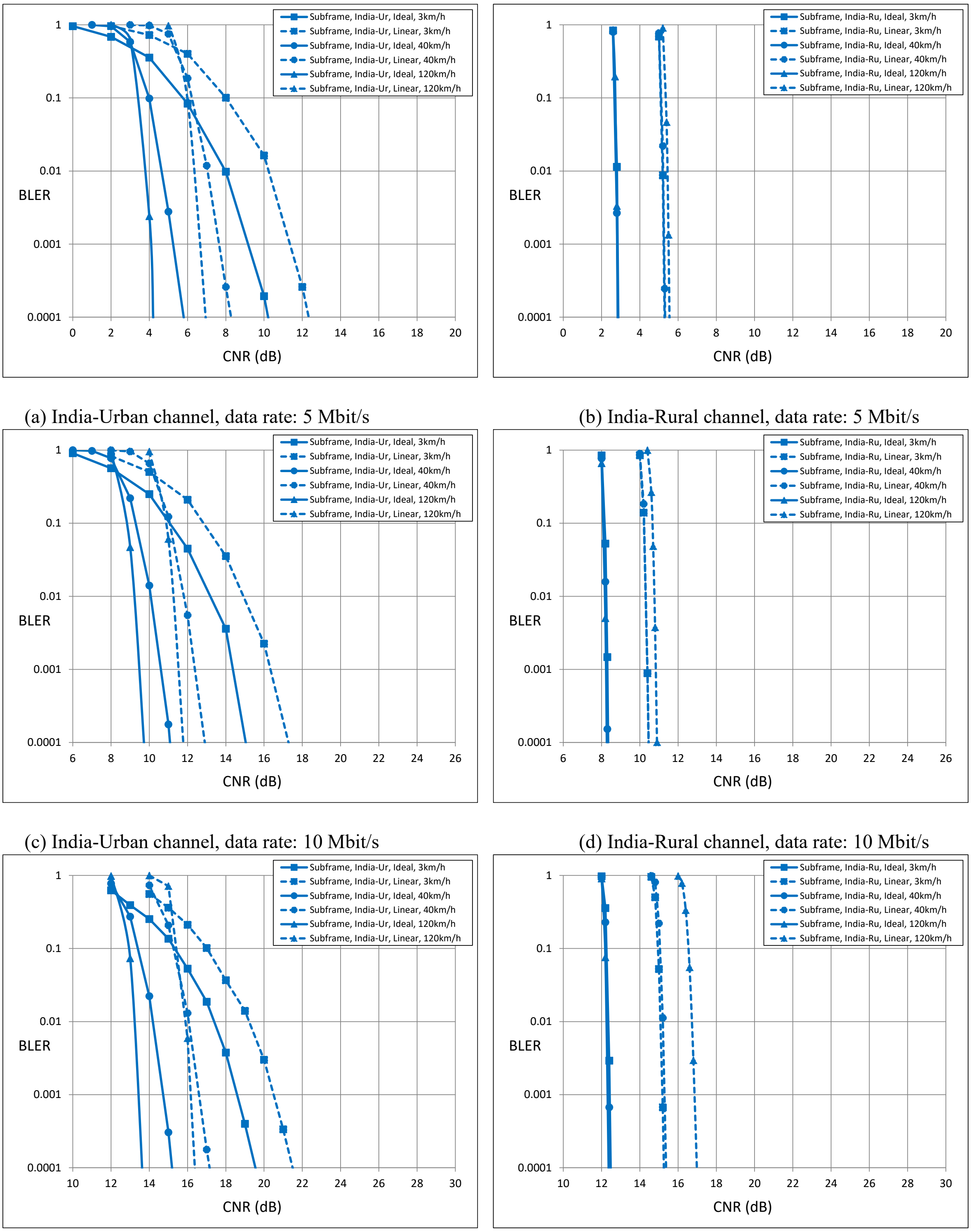
TABLE 53

Configuration for data channels (8 MHz BW)

		Svc1	***Svc2***	***Svc3***
ATSC 3.0	Code Rate	8/15		
	Constellation	QPSK	16-NUC	64-NUC
	Data Rate	5.36 Mbit/s	10.73 Mbit/s	16.09 Mbit/s
	Required CNR (AWGN)	1.2 dB	6.4 dB	10.4 dB

FIGURE 159

Performance of the ATSC 3.0 subframe over India-Urban and India-Rural channels



(a) India-Urban channel, data rate: 5 Mbit/s

(b) India-Rural channel, data rate: 5 Mbit/s

(c) India-Urban channel, data rate: 10 Mbit/s

(d) India-Rural channel, data rate: 10 Mbit/s

(e) India-Urban channel, data rate: 15 Mbit/s

(f) India-Rural channel, data rate: 15 Mbit/s

4 Network complexity evaluation

Broadcast operators recognize spectral efficiency as an essential factor in network design. The reason is that the complexity of the network depends on the trade-off between throughput and service reliability. Specifically, the network complexity is a function of the number and size of towers used in the network. Given the necessary infrastructure (tower deployment) to reach the service target, one can evaluate the site logistics, transmission power requirement, and the backbone connectivity required for maintaining single frequency network (SFN) synchronization. Even if the SFN operator can reuse existing infrastructure, the number of operational towers and physical layer efficiency dominate the infrastructure required for each protocol standard. Given the target service area and QoS, the protocol efficiency can be directly translated into the network complexity.

As a practical example, a study was made in the urban metropolis of Bengaluru, India. The Bengaluru plateau is notable for this comparison because of the relatively flat terrain where transmissions need to rely on a low-power/low-tower (LPLT) infrastructure. This work is based on handheld use cases in LPLT SFN environments. The analysis uses data from the existing telecom stations, clutter (terrain type data), and population data; thereby conforming with an actual deployment. Using this input data, the number of SFN transmitters (NoST) required to ensure a 95% reception probability in the target area of interest (AoI) is evaluated for ATSC 3.0. The simulations use data from existing mobile telecom sites in Bengaluru, where a total of 1576 sites are available within the AoI. The parameters for the test scenario are shown in Table 54.

The simulation results in Fig. 160 show the number of sites needed for network feasibility. Given the site location data, an optimal subset of those tower sites is determined to fulfil the QoS across the AoI with minimal overlap. According to the results for *Svc*1, ATSC 3.0 requires 223 SFN transmitters to be operated. Likewise, 415 sites are needed for 10 Mbit/s service (*Svc*2).

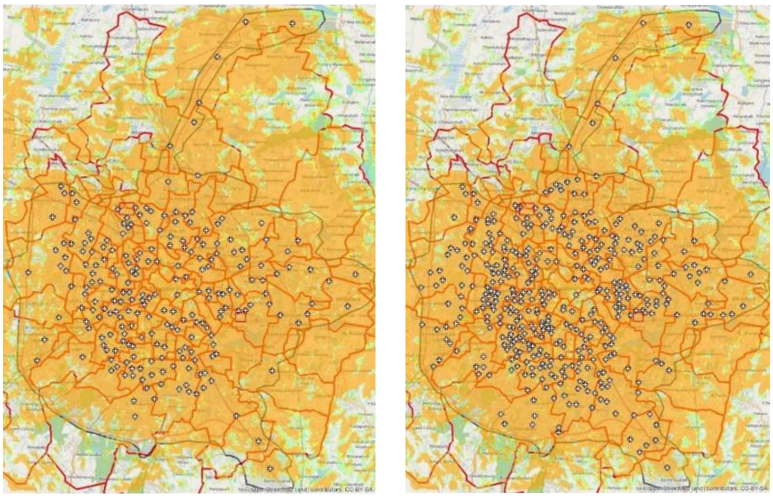
TABLE 54

Scenario description

Centre frequency	500 MHz
Transmit power	40 W (46 dBm)
Antenna height	14-100 m (avg. 32 m)
Antenna type	Omni-directional
Antenna gain	9 dBi
EIRP	55 dBm
Reception mode	Handheld Indoor (3 km/h)
Network type	LPLT
Antenna type	Omni-directional, Colinear antennas, Vertically polarized
Antenna gain	−9.5 dBi
Noise figure	7.5 dB
Outdoor signal Std. dev. (Log-normal)	5.5 dB (Rec. ITU-R P.1546-6)
Coverage target	95%

FIGURE 160

Required tower deployment for ATSC 3.0: (a) *Svc*1 (223 sites), (b) *Svc*2 (415 sites)



(a) (b)

5 Laboratory test results

For the laboratory test, a commercial exciter and a professional receiver were used. The transmission parameters for the laboratory test are summarized in Table 55. The broadcasting bandwidth in use in South Korea, 6 MHz, and the centre frequency of 768 MHz, the experimental station frequency available in South Korea, were considered. For the mobile broadcasting environment, transmission parameters using Convolutional Time Interleaver (CTI) with a depth of 1 024 and FI, including 8K FFT size, were considered. TU-6 channel and India-Urban channel were considered as the receiving channel environment, and laboratory tests were performed considering receiver movement speeds of 3 km/h, 40 km/h, and 120 km/h in both channels, respectively.

TABLE 55

Laboratory physical layer description

PHY transmission parameters for ATSC 3.0	
Centre frequency	768 MHz
Bandwidth	6 MHz (Occupied bandwidth = 5.83 MHz)
FFT size	8192
Guard interval	GI6_1536 (222.22 us)
Subcarrier spacing	0.844 kHz
Pilot pattern	SP4_2
Time interleaver	CTI with a depth of 1024
Frequency interleaver	On

TABLE 56

Laboratory evaluation assumptions

Reception conditions for ATSC 3.0	
Channel model	TU-6, India-Urban
UE mobility	3 km/h, 40 km/h, 120 km/h
Number of Tx antenna	1
Channel estimation	DFT-based

In this laboratory test, four target data rates of 2.5 Mbit/s, 5 Mbit/s, 10 Mbit/s, and 15 Mbit/s were considered for each service class, whose configurations are described in Table 57. As initial performance results from laboratory tests, the SNR values required to achieve BLER = 10^{-4} over an AWGN channel are presented as the baseline performance for each service class. The performance measurement results in terms of BLER of the ATSC 3.0 subframe corresponding to the data payload are presented in Fig. 161. Note that only subframe performance excluding bootstrap and preamble parts was measured in the laboratory test.

The measurement results show that the required SNR strongly depends on the target data rate and mobility. In most cases, a significant amount of time diversity gain is observed thanks to time interleaver. In general, the slope of BELR curves become steeper as the velocity of UE increases. However, if the target data rate is 15 Mbit/s, decoding is not possible for a UE velocity of 120 km/h in both TU-6 and India-Urban channels. The overall BLER performance trend shows a very similar pattern between the TU-6 and India-Urban channels. The India-Urban channel has a larger delay spread and a greater number of multipaths than the TU-6 channel, so there appears to be a performance difference of up to 1 dB.

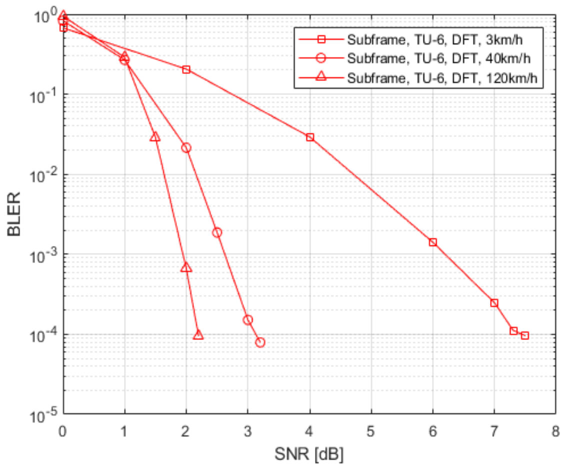
TABLE 57

Laboratory configuration for data channels corresponding to service classes (6 MHz BW)

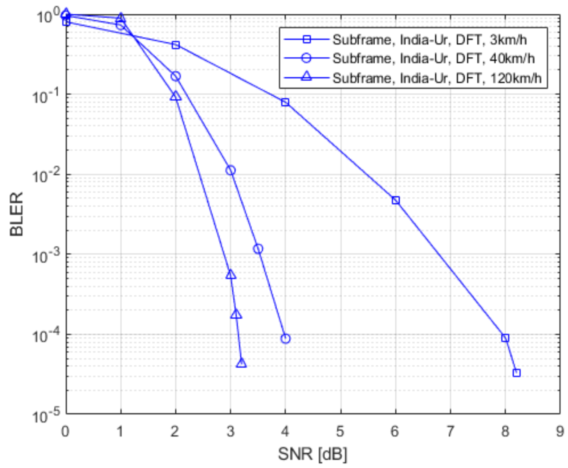
		Svc0	**Svc1**	**Svc2**	**Svc3**
ATSC 3.0	Code rate	5/15	5/15	7/15	10/15
	Constellation	QPSK	16-NUC	64-NUC	64-NUC
	Data rate (Mbit/s)	2.73	5.47	11.53	16.51
	Required SNR measured through laboratory test (AWGN) (dB)	−0.8	3.5	9.6	13.8

FIGURE 161

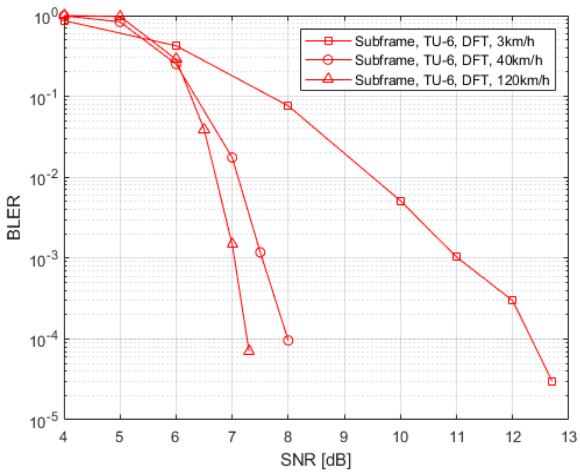
Performance of the ATSC 3.0 subframe over TU-6 and India-Urban channels



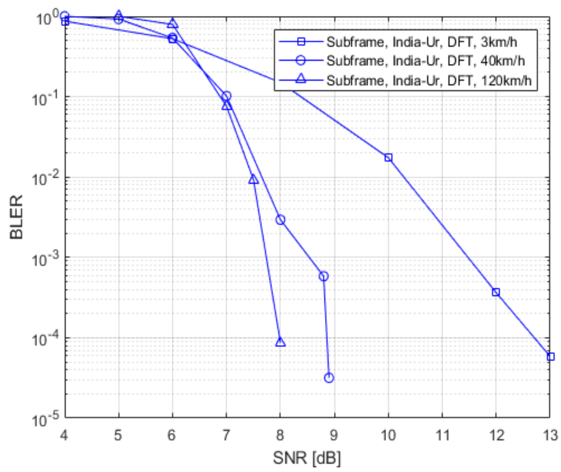
(a) TU-6 channel, data rate: 2.5 Mbit/s



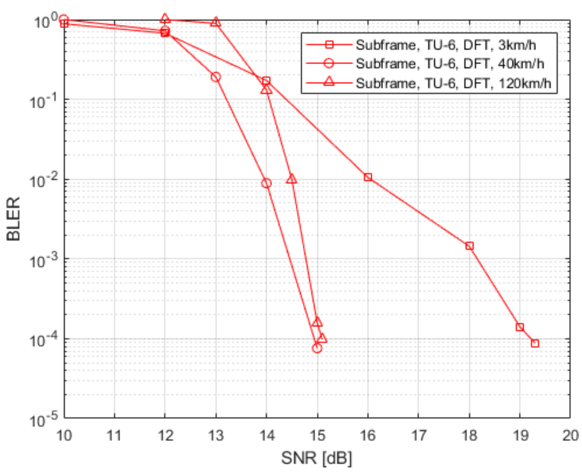
(b) India-Urban channel, data rate: 2.5 Mbit/s



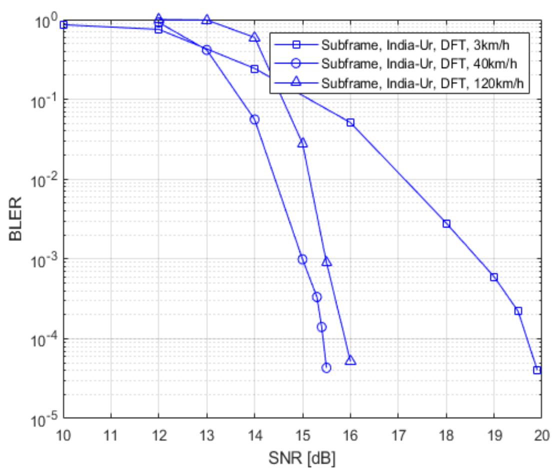
(c) TU-6 channel, data rate: 5 Mbit/s



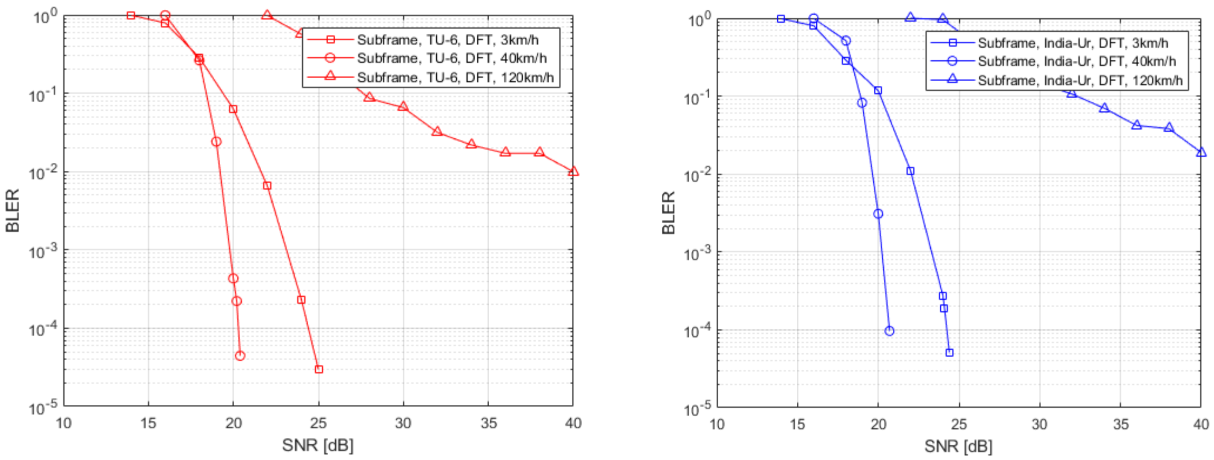
(d) India-Urban channel, data rate: 5 Mbit/s



(e) TU-6 channel, data rate: 10 Mbit/s



(f) India-Urban channel, data rate: 10 Mbit/s



(g) TU-6 channel, data rate: 15 Mbit/s

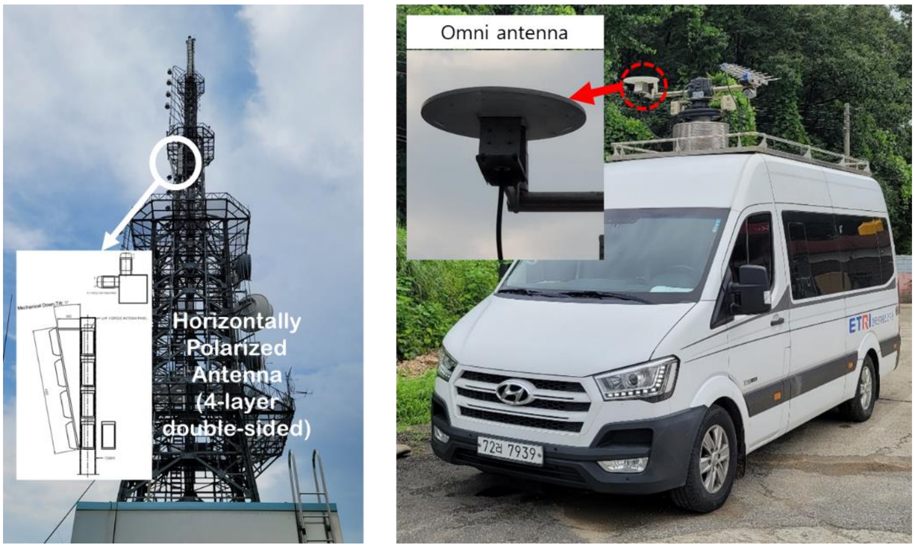
(h) India-Urban channel, data rate: 15 Mbit/s

6 Field test results

The field test used the same ATSC 3.0 hardware systems as in the laboratory test, as well as the transmission parameters in Table 55. The field test was conducted in the north Gyeonggi-do area of South Korea. For the transmission, a 4-layer double-sided horizontally-polarized antenna was used. The transmission power was set to 100 watts. For the signal reception and mobile measurement, a test vehicle equipped with a disk-shaped omni-directional antenna was used as shown in Fig. 162(b). Note that in the laboratory test, only the subframe performance corresponding to the data payload was observed, but in the field test, the overall performance of the physical layer including bootstrap and preamble was measured.

FIGURE 162

Transmission and reception facilities



(a) Transmit antenna

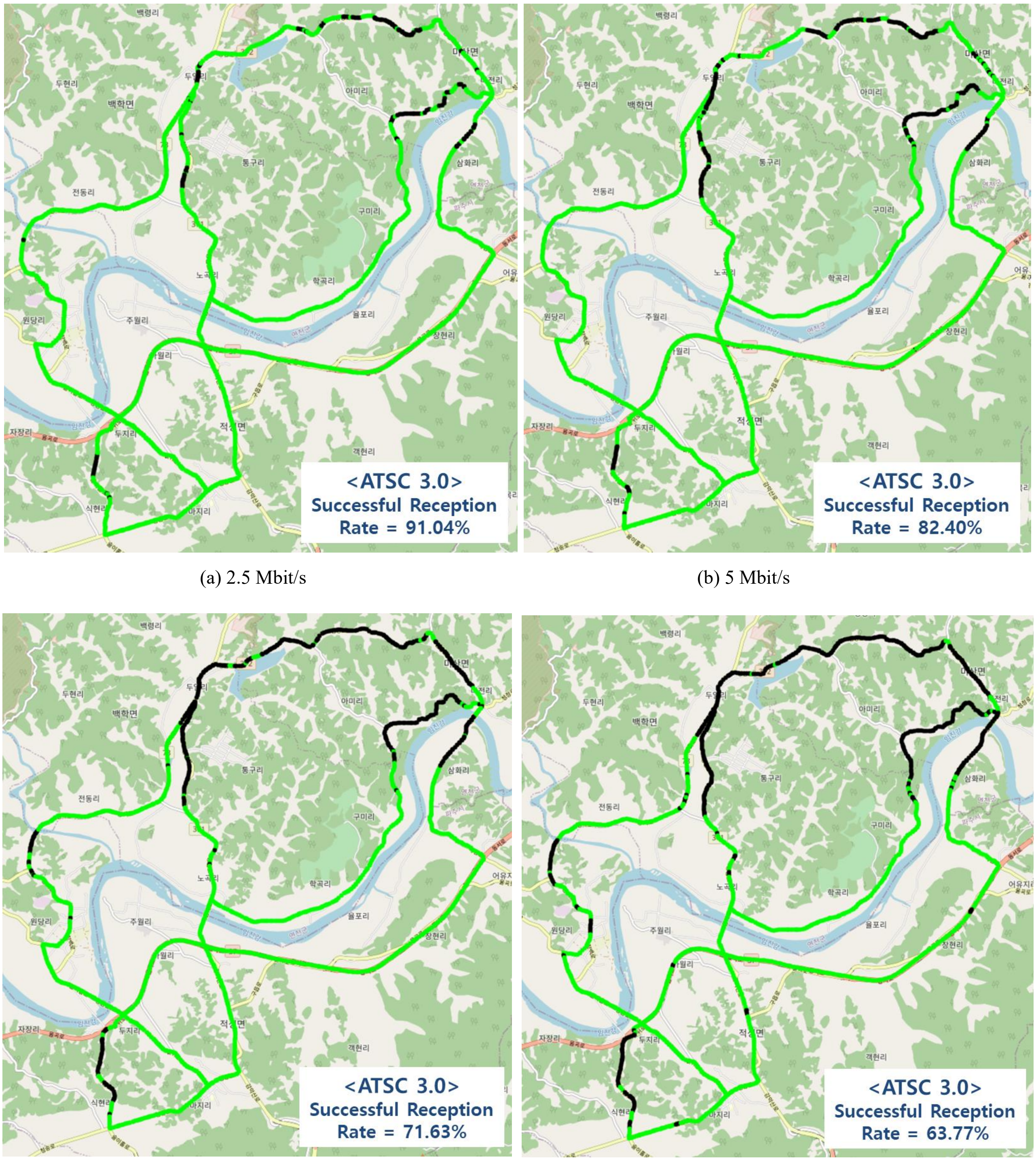
(b) Test vehicle and receive antenna

Figure 163 shows the signal receivability recorded throughout the test route. Whenever the signal decoding failed, the corresponding spot was marked in black, whereas the green dots indicate that the received signal was successfully decoded during the corresponding unit record duration. Each dot is a result saved every second, and was recorded only when the vehicle was moving to prevent duplicate data from being recorded through measurements. The transmitting station is located at the southeast area of the test route, and as there is a low mountainous area to the north, it is not easy to secure LOS in that area, so the received field strength is quite low. For this reason, as the target data rate increases, the area where reception fails gradually expands in the northern section. As a result, the reception success rate was observed to drop from 91% at 2.5 Mbit/s to 64% at 15 Mbit/s.

Figure 164 illustrates the successful reception rate with respect to received field strength, which equivalently indicates the erroneous second rate (ESR) metric. As shown in Fig. 164, 2.5 Mbit/s, 5 Mbit/s, 10 Mbit/s, and 15 Mbit/s required −87.3 dBm, −84.6 dBm, −76.9 dBm, and −72.9 dBm of field strength to ensure successful reception rate of 95%, respectively.

FIGURE 163

Signal receivability corresponding to each target data rate



(a) 2.5 Mbit/s

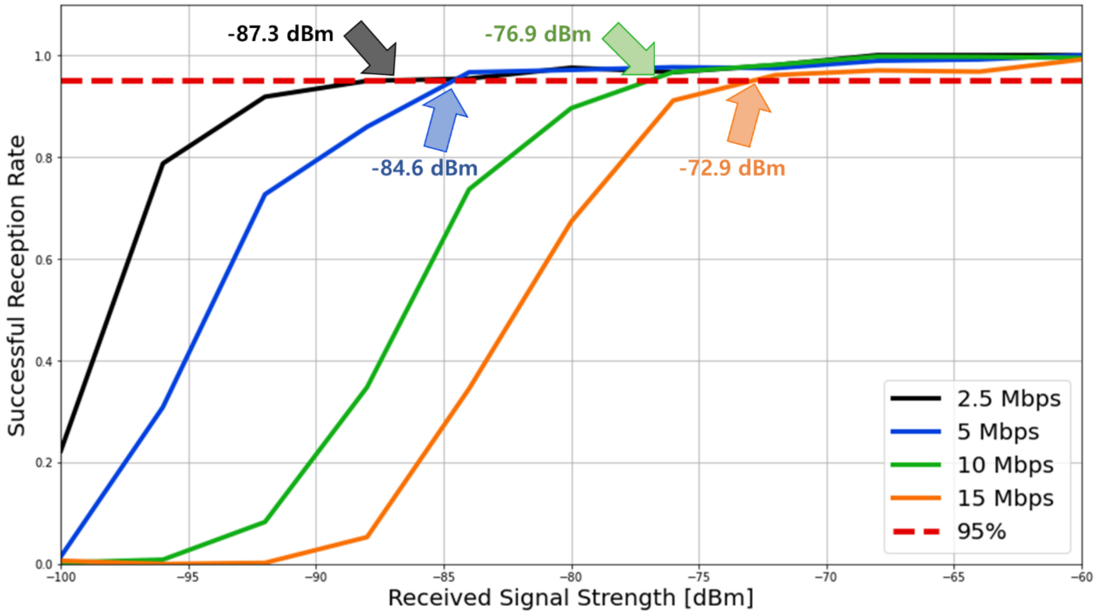
(b) 5 Mbit/s

(c) 10 Mbit/s

(d) 15 Mbit/s

FIGURE 164

Mobile reception reliability for various target data rate



7 Summary

This study verifies the performance of ATSC 3.0 physical layer under mobile reception conditions. The data represents comprehensive performance evaluation results from computer simulation, laboratory test, and field test. Various target data rate scenarios were considered, and the evaluation was conducted assuming a realistic transmission and reception environment.

Annex 11

France: LTE-based 5G broadcast trial during the 2024 Olympic and Paralympic Games

1 Summary

During the 2024 Olympic and Paralympic Games in France, an LTE-based 5G broadcast trial was deployed in several cities (Paris, Nantes, Bordeaux) in France using different network arrangements. This trial was the result of the efforts of France Televisions, Radio France, Arte, France Médias Monde, Rohde & Schwarz, Qualcomm Technologies, Ateme, Xiaomi, towerCast and TDF.

TDF deployed new transmitters across three areas to offer the widest coverage possible while coping with the existing UHF frequency usage, in a context of high pressure on the spectrum use do the Olympics and Paralympics Games which required high amount of spectrum for PMSE uses. Outdoor portable reception to the users was the main target, with mobile in-car or indoor reception seen as a plus where possible; the network cores and transmitters were provided by Rohde Schwarz; using Ateme encoding solution; and the receivers used for the trial were provided by Xiaomi using a Qualcomm technology.

Throughout the Olympic and Paralympic Games, the broadcast configuration mainly used eMBMS (Release 12) with MCS14[12] (16-QAM) achieving 3.7 Mbit/s of capacity in 5 MHz bandwidth and 7.4 MHz in 10 MHz bandwidth, considering the current limitations of receiver performance to 60% of the available raw capacity.

The content was a mix of three HD TV services and two radio services, with various encoding configurations permitted by the use of two different bandwidths (5 and 10 MHz, depending on the area covered). The three HD TV services were the live versions of "France 2 HD" from France Television – especially offering live content from the Olympic and Paralympic Games during the various events, "Arte" from Arte, and "France 24" from France Médias Monde, while the two radio services were "franceinfo:" and variations of "France Bleu" (depending on the area) from Radio France. An additional TV service (demo loop) was offered by TDF on the Nantes area (thanks to 10 MHz bandwidth).

The main goal of the trial was to go beyond what was demonstrated during the Roland-Garros 2023 experiment (see Annex 8) both on the technical side and on the end-user side:

– Promote this technology and its emergence as the 3rd axis of DTT modernization in France
– Launch a strong partnership collaboration with content providers and manufacturers ecosystem
– Carry out a large-scale trial, with a significant quantity of devices for credible feedback
– Test new technical concepts particularly on wide area (impossible to simulate in labs) – SFN, dropouts, …
– Demonstrate technology use cases, particularly using press and media, to reach as many people as possible

2 Participants

– France Televisions – National Public TV Content Provider – EBU member (https://www.francetelevisions.fr/)
– Radio France – National Public Radio Content provider (https://www.radiofrance.fr/)
Arte – The European Culture Channel (https://www.arte.tv/en/)
– France Médias Monde (https://www.francemediasmonde.com/en/)
– TDF – Broadcast Network Operator and Headend Manager – BNE and EBU member, (https://www.tdf.fr)
– towerCast – Broadcast Network Operator
– Xiaomi Corporation (http://www.xiaomi.com/)
– Rohde & Schwarz (https://www.rohde-schwarz.com)
– Qualcomm Technologies (https://www.qualcomm.com)
– Ateme (https://www.ateme.com)

[12] MCS21 (64-QAM) was also shortly trialled, but it is clear from a reception quality point of view and the measurements made that such a high-order modulation is not adequate to offer a large enough portable outdoor coverage despite the attractive increase in throughput it offers. As a consequence, the experiment focussed on MCS14.

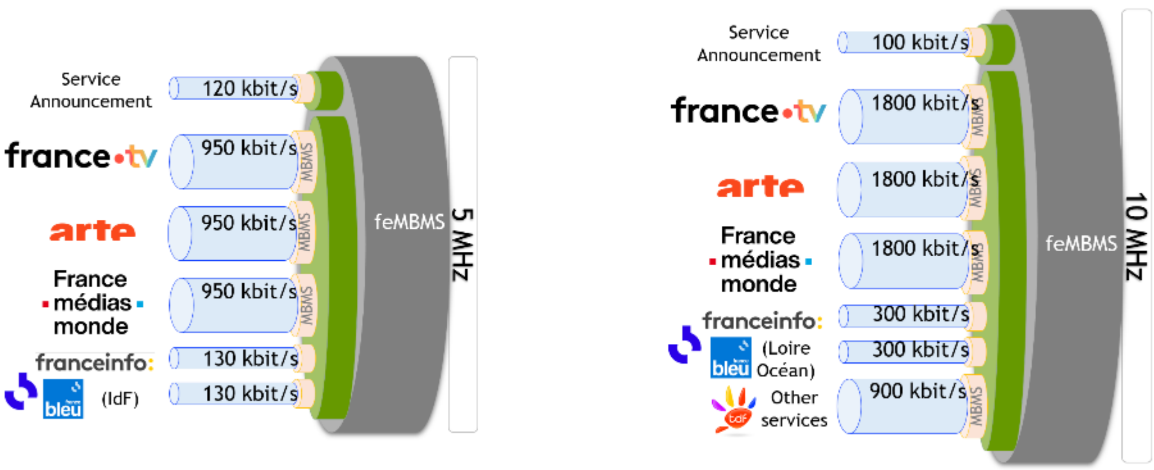
3 Services

Both linear radio and TV services were offered for the duration of the experiment. Due to the different channel bandwidths available, one multiplex has been deployed on the Paris and Bordeaux areas on one side and another multiplex on the Nantes area on the other side.

The composition of the multiplexes was very similar in terms of contents with three common TV programmes, one common radio programme and one specific radio programme on each of the three areas, and the addition of a specific TV programme for the Nantes area. All programmes were formatted for DASH streaming, using HEVC for video coding and AAC for audio coding. They mainly differed in the encoding quality, the 10 MHz bandwidth providing sufficient room for high bitrates both for radio and TV content.

FIGURE 165

Multiplexes composition and bitrates for the 5 MHz bandwidth (left) and the 10 MHz bandwidth (right)



With the 5 MHz bandwidth and considering MCS14 for the services, the available capacity is around 3.4 Mbit/s for the different programs (with the limitation to the use of 60% of the resources in the channel), while the signalling service uses a more robust MCS6. A small amount of the overall capacity is used as a headroom for slight variations in the encoding rates of the various components. With the limited available capacity in this 5 MHz bandwidth, video resolution was limited to 720p, while audio coding rate reached a maximum of 128 kbit/s.

Extending the bandwidth to 10 MHz allowed to accommodate an additional TV program in the multiplex, while raising the video resolution to 1080p, audio coding rate to 256 kbit/s and still maintaining an MCS14.

4 Experimentation dates

– 10 April 2024 – 30 September 2024.

5 Location

Three main areas of interest were defined for this experiment:

– Paris and surroundings (France)

– Nantes (France)

– Bordeaux (France)

6 Technologies

This LTE-based 5G broadcast experiment was limited to 3GPP eMBMS (Release 12) due to the focus on the use of end-user terminals readily available supporting the wanted functionalities and in a sufficient volume[13].

7 Spectrum and frequencies

Due to the use of Release 12 and the capabilities of the selected end-user devices, the spectrum planning for this experiment was focused on the downlink component of 3GPP LTE Band 71 (FDD band with 663-698 MHz Uplink / 617-652 MHz Downlink).

Taking into account the heavy UHF spectrum use for DTT in France (as can be seen below), and the exceptional frequency planning situation that an event such as the Olympic and Paralympic Games entails in terms of spectrum use for PMSE and other needs (see the specific Spectrum Management Plan), the following channels were identified for the experiment after a thorough evaluation of the potential impact on PMSE:

– 5 MHz in TV channel 39 (617-622 MHz) – Paris area
– 10 MHz in TV channels 39-40 (620-630 MHz) – adjacent to DTT on channel 38 – Nantes area
– 5 MHz in TV channel 41 (632-637 MHz) – Bordeaux area

On the Paris area, the spectrum planning was conceived from the start for an SFN deployment of towerCast and TDF transmitters: in a Release 12 configuration, such a deployment is very challenging as the guard interval is limited to 16.6 µs (5 km inter-site distance) while the sites to be deployed are separated from 1.5 to 11 km. This required a careful planning of both transmitter ERPs and initial delays to try and serve as much areas as possible.

Despite this thorough planning, it was known from the start that the service area would not be perfect because of the selected sites, and the service area was optimized to best serve the inner parts of Paris city where Olympic and Paralympic events were taking place (Trocadéro, Champs de Mars, Concorde, …).

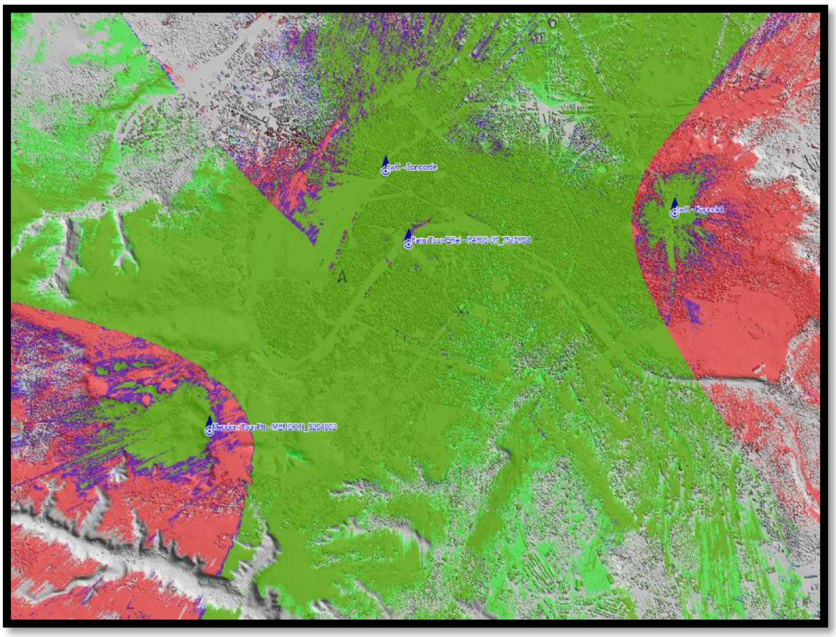
[13] 250 end-user terminals were made available to technical and non-technical people, both from stakeholders and the general public, to discover the service offering of this experiment, assess the quality of reception and provide feedback on the usages and perceived quality (image, sound, latency, …).

FIGURE 166

Existing DTT spectrum use in France (channel coverage areas in blue), from channel 39 (614-622 MHz, left) to channel 43 (646-654 MHz, right)

FIGURE 167

Theoretical experiment service area (for a good coverage using MCS14 / portable outdoor reception): green = 99% of locations served, blue = 95% of locations served, red < 95% of locations served



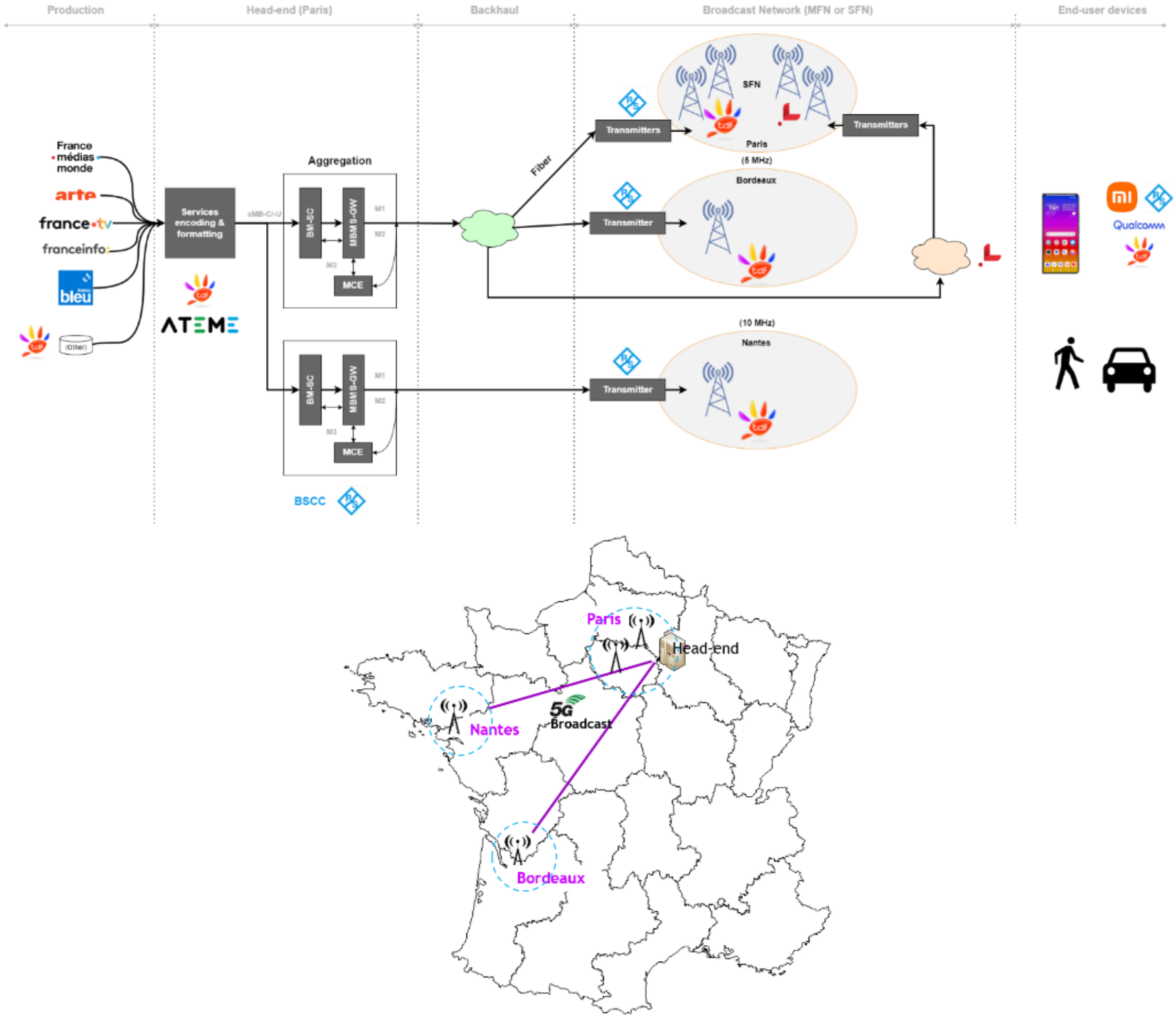
8 Equipment and infrastructure

While the content production was directly made by the different content providers (France Televisions, Arte, France Médias Monde, Radio France), the encoding and formatting was centralized in the Romainville technical centre, after collecting the different programs from a common interconnexion point. Two head-ends were installed in Romainville as well (both using a dedicated BSCC from Rhode & Schwarz) to create two multiplexes, each one dedicated to a specific bandwidth.

The resulting multiplexes were delivered through TDF's backhaul links to the broadcasting sites; the 5 MHz multiplex was also delivered to towerCast through the common interconnexion point to feed their own transmitters over the Paris area.

FIGURE 168

Schematic diagram of the experiment



The TDF sites used for this experiment are part of the existing broadcast infrastructure: the Eiffel tower in Paris, and the Nantes and Bordeaux sites have been operating national DTT multiplexes for several years now (starting with DVB-T and SD content back in 2008, transitioning to a majority of HD content in 2014 and now also equipped with DVB-T2 transmitters for one multiplex broadcasting UHD content). The Meudon site south-west of Paris has been operating a DAB multiplex for several months as well. These four sites have been fitted with specific equipment to cater for the experiment:

– Specific V-polarized antennas were deployed close to existing antennas to respect the constraints set forth in the planning phase; unlike the existing antennas, these were merely directional antennas, with powers ranging from 1 kW ERP (Nantes, Bordeaux, Meudon) to 5 kW ERP (Eiffel Tower). Since the majority of DTT transmissions in France use H-polarized antennas, the use of V-polarized antennas provided an additional protection for DTT, in case of saturation risks, for example in the Meudon transmitter area where the 5G Broadcast transmission is not collocated with DTT transmission.

– Specific filters were also installed at the output of the Rohde & Schwarz xxx W transmitters, and specific feeders carried the output signal to the dedicated antennas. The filters were tailored for a strict 5 MHz filtering on the Paris area to protect the PMSE usage. A regular 8 MHz DTT filter was used for Bordeaux, and a specific filter was designed for the 10 MHZ bandwidth in Nantes (unusual in the broadcast landscape).

TABLE 58

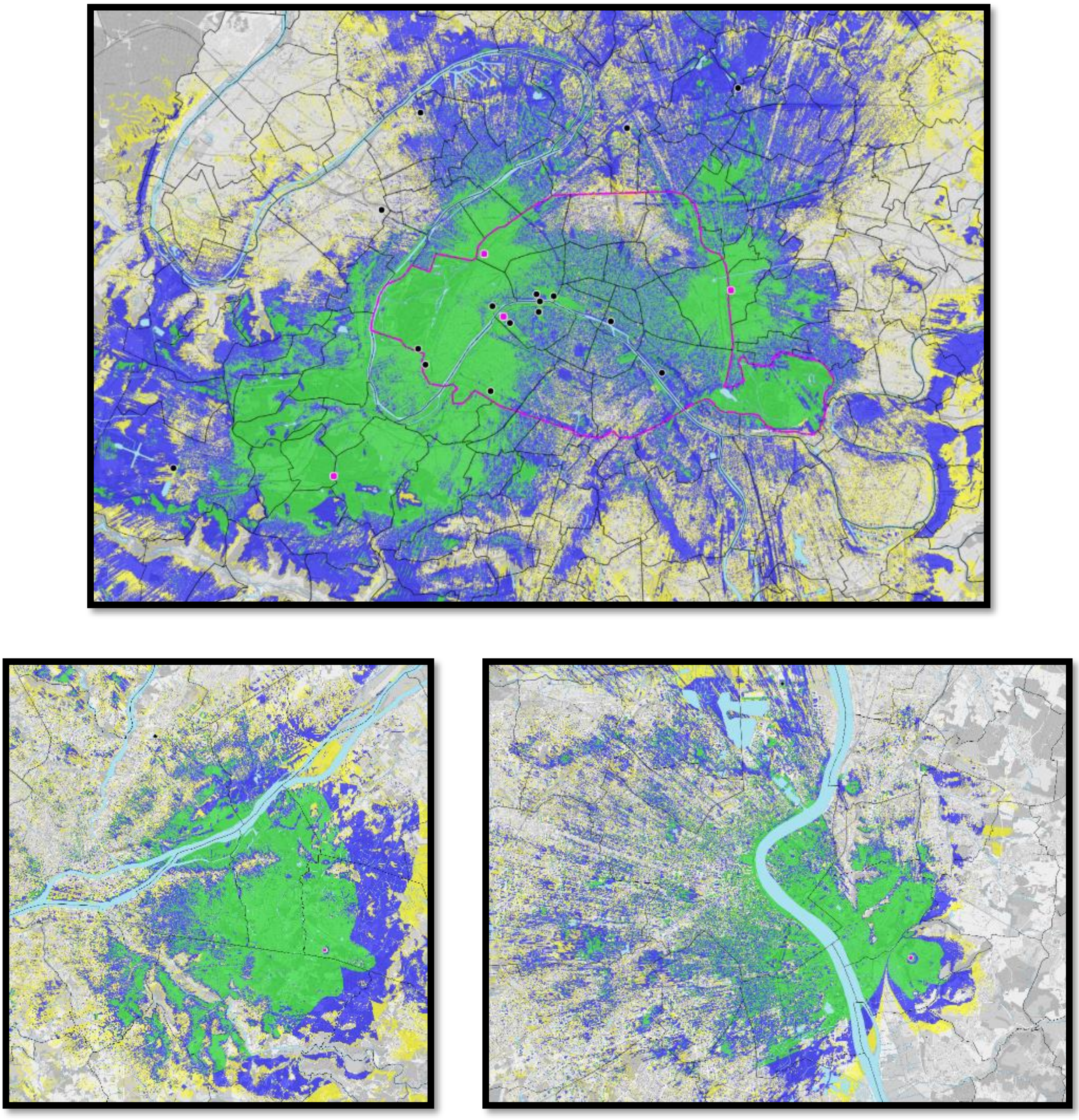
Summary configuration of the sites used during the experiment

Area	Sites	ERP	Frequency planning
Paris	Eiffel Tower (TDF) Meudon (TDF) Concorde (towerCast) Bagnolet (towerCast)	5 kW 1 kW 600 W 1 kW	SFN
Nantes	Nantes Haute Goulaine (TDF)	1 kW	MFN
Bordeaux	Bordeaux Bouliac (TDF)	1 kW	MFN

On the Paris area, four sites were used in SFN for the duration of the experiment: TDF's Eiffel Tower and Meudon sites, while towerCast deployed two additional sites (North and East of the city respectively). In addition to the synchronous feeding of these sites and the adjusted initial delays of the transmission, a unique PCI (Physical Cell Identifier) was assigned to each transmitter to allow an easy identification of each individual contribution.

FIGURE 169

Theoretical coverage[14] over the Paris area (top), Nantes area (bottom left) and Bordeaux area (bottom right)
green = very good portable / good vehicular (> 76 dBµV/m),
blue = good portable / average vehicular (> 67 dBµV/m),
yellow = average portable / poor vehicular (> 63 dBµV/m)



14 Using TDF's proprietary propagation model (ITU-R P.526 based) and a high-resolution 4 m DEM plus clutter information.

9 Devices and mobile application

Throughout the course of the experiment, commercial devices from Xiaomi have been extensively used to receive the various programs proposed. These devices have gone through a customization process to extend their capabilities beyond the current commercial offering:

– MBMS middleware update to enable frequency agility (allowing the application to trigger a frequency rescan without any manual adjustment). For the time being, the middleware only handles the first found multiplex / frequency that offers LTE-based 5G Broadcast, other possible multiplexes are ignored.

– 5G Broadcast reception in the whole B71 frequency range (i.e. not limited to the downlink part of LTE band 71).

– Support of 5 and 10 MHz channels, using standard LTE waveform numerology, for 5G Broadcast reception.

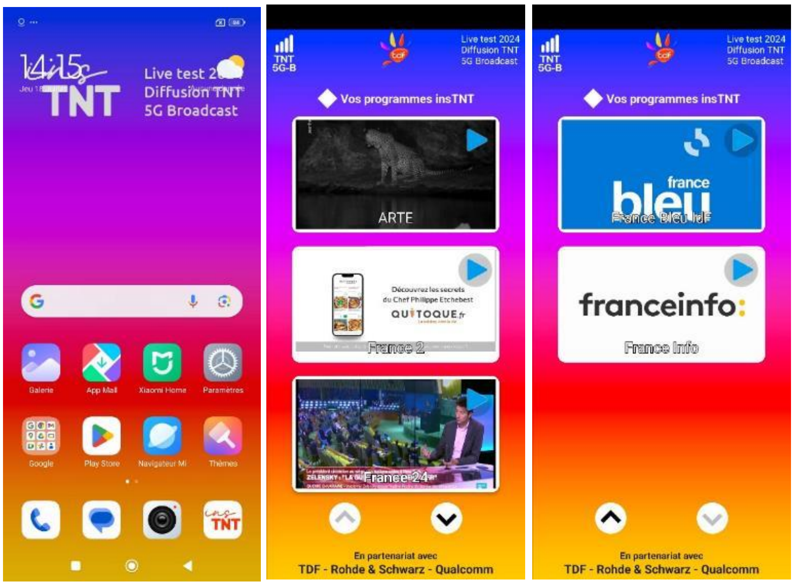
– Broadcast and broadband enabled: the device is broadcast-only when the 5G broadcast app is running. Broadband can be used with a standard SIM-card (in a second slot), but not simultaneously with Broadcast.

In parallel to this customization, a dedicated LTE-based 5G Broadcast application was developed to offer an attractive access to the radio and television programs made available during the experiment, with easy and almost instantaneous switch from one program to the other. Extensive laboratory tests involving Xiaomi, Qualcomm, Rhode & Schwarz and TDF were made to test and validate both the customization and application before releasing several hundreds of user-devices in the field, along with fine tuning of the parameters on the encoder and core network.

This release was followed by the launch of a companion website (https://www.instnt.fr/) offering directions on the use of the application, access to the theoretical coverage and the ability to provide feedback on the experiment.

FIGURE 170

Screenshots of the customised commercial device and the insTNT (“instant”) application



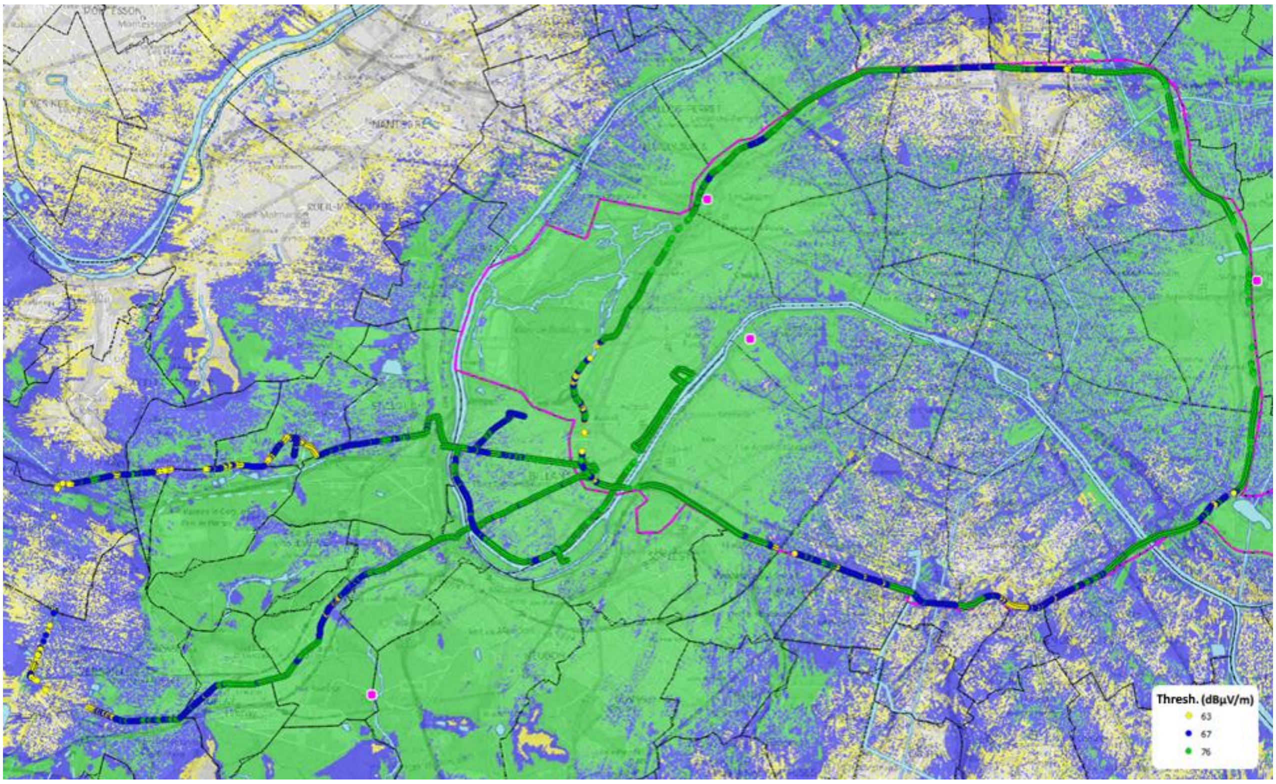
10 Measurements

Measurement campaigns were made before and during the Olympics and Paralympics Games, to qualify the coverage with respect to the theoretical coverage on one side, and to assess the received signal quality on the end-user devices.

The qualification of the real coverage used a professional field-measurement equipment configured to examine the signals in the designated frequency and channel bandwidths, using a measurement car fitted with an omnidirectional roof-top antenna. The available results show a pretty good match between the theoretical coverage (using TDF's proprietary propagation model derived from Recommendation ITU-R P.526 and a high-resolution 4m DEM plus clutter information) and the real coverage in urban and sub-urban areas, with a centred prediction error and less than 6 dB standard-deviation; in dense urban areas like Paris, the prediction error is still centred but the standard-deviation degrades with a value around 9 dB.

FIGURE 171

Coverage measurement versus theoretical coverage, Paris area (5 MHz bandwidth, 617-622 MHz)



In addition to pure coverage measurements, subjective measurements were made using a pair of Xiaomi devices to assess the perceived quality of the available programs (either audio/video for television programs or audio only for radio programs). These subjective measurements were accompanied by simultaneous recording of standard LTE metrics: RSSI (Received Signal Strength Indicator), RSRP (Reference Signal Receive Power), SINR (Signal to Interference plus Noise Ratio) and RSRQ (Reference Signal Receive Quality) using a dedicated prototype equipment providing measurements in Band 71.

Analysing the different metrics, it was remarked that in a broadcast reception situation as the one encountered in this experiment, and even in the case of SFN reception, RSRQ had a really low dynamic (less than 2 to 3 dB) and was always measured above −7 dB over all the routes that were examined. As it stands, it was decided to discard this metric in our analysis. Only RSSI was used as a cross-check of the potential coverage and decided to focus on RSRP[15].

FIGURE 172

Objective and subjective measurement – MCS14, Radio France area (pedestrian)

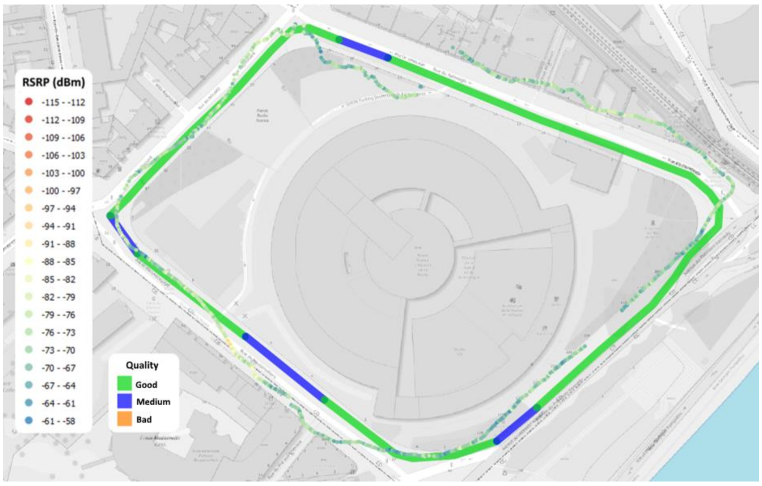
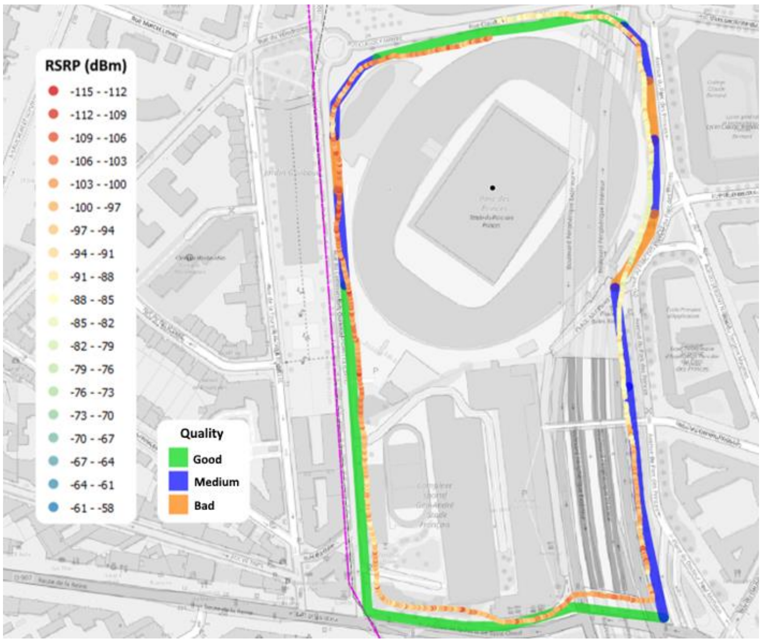


FIGURE 173

Objective and subjective measurement – MCS14, Parc des Princes area (pedestrian)



The measurements were made for outdoor portable reception using pedestrian routes, manually recording the "average" perceived quality on the pair of Xiaomi devices (handheld devices mostly in portrait mode) with three levels:

– Good: no frame dropout, no video/audio impairments.

– Medium: short video/audio artifacts, quickly recovered by the end-user device.

[15] SINR analysis was in also focus but is not presented in this contribution as the same remarks hold true as well, albeit the scales differ (dB for SINR and mostly positive values, dBm for RSRP and negative values).

– Bad: long (> 1s) video/audio impairments or complete lack of audio or video.

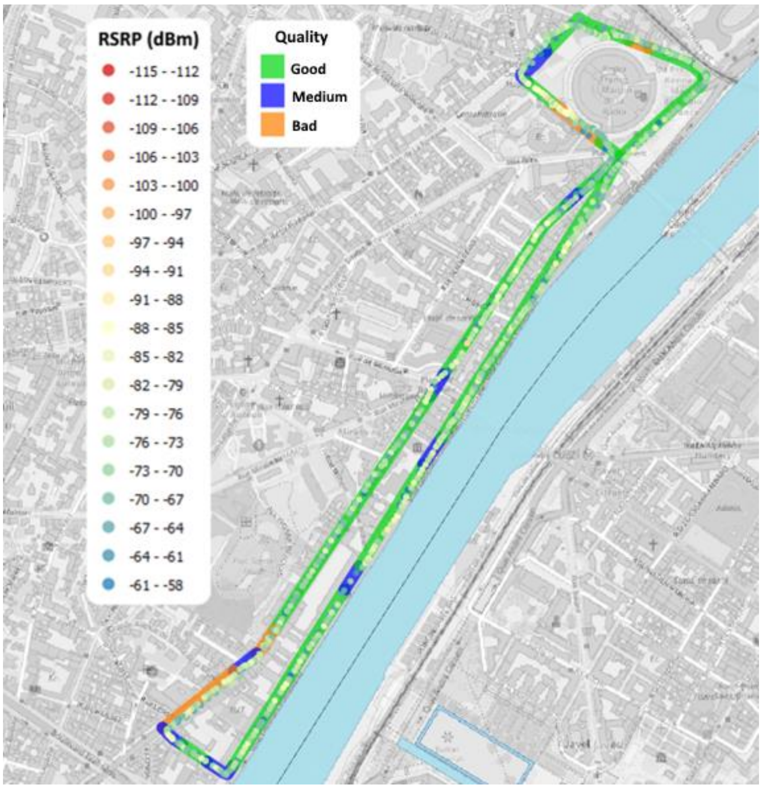
The key LTE metrics were automatically recorded every second from the dedicated equipment fitted with an omnidirectional antenna and a GPS antenna held above a backpack.

As shown on the two previous Figures, bad reception can happen for the lower RSRP values (below −90 dBm or even lower). Nevertheless, some areas with low RSRP values offer medium to good reception as well, meaning that for the time being it is quite difficult to correlate directly a perceived quality with objective measurements. This situation might be due in part to the set-up of the measurements with a hand-held device on one side to assess the perceived quality and a specific equipment with its own antenna and a slightly different location measuring the different metrics.

Depending on the reception situation, we also observed in some cluttered areas quite a different behaviour between the two end-user devices, with one device offering a very good reception quality while the other one struggled to cope with numerous impairments.

FIGURE 174

Objective and subjective measurement – MCS14, Seine area (vehicular)



The measurements were also made for in-car reception, with the end-user device positioned under the windscreen (in landscape mode), and the measurement and GPS antennas on the rooftop of the car.

Different car models were used for these measurements, and we noticed that the type of windscreen used could severely impact the in-car quality of reception, especially when athermal windscreens were present. In this case, the built-in antenna seems to struggle to catch a good quality signal, resulting in a bad or (at best) medium perceived quality.

The impact of measuring the perceived quality and different metrics with two different devices is even more important in the vehicular measurements, as the specific antenna used to measure the LTE metrics is rooftop / external, while end-user reception occurs in the car. It is then even more difficult to correlate the metrics with the perceived quality to derive network planning rules for this type of reception, in the current situation.

FIGURE 175

End-user device positioning for in-car reception

Unfortunately, for the time being it was not possible to extract directly the LTE metrics from the hand-held device: although the device itself is not a professional measuring equipment, it is the one that serves for the end-user usage and in a way is the reference on which the perceived quality assessment was based; it is assumed that accessing the LTE metrics from within the devices will offer a better understanding of the relationship between the different metrics and the perceived quality.

Nevertheless, the currently available metrics allowed a precise analysis of the SFN deployment over the Paris area: thanks to the use of different PCI for each transmitter, it was possible to distinguish between each received component in areas of signal superposition between the different transmitter and analyse the possible root causes of malfunction.

Figures 176 and 177 show the resulting perceived quality when the SFN is not operational compared to when it is operational on an area close to the Meudon transmitter:

– As can be seen, when the Eiffel Tower transmitter is switched on, the perceived quality is adversely affected, leading to large areas where the correct reception of the various programs is difficult when signals from both the Eiffel Tower and Meudon transmitters are received.

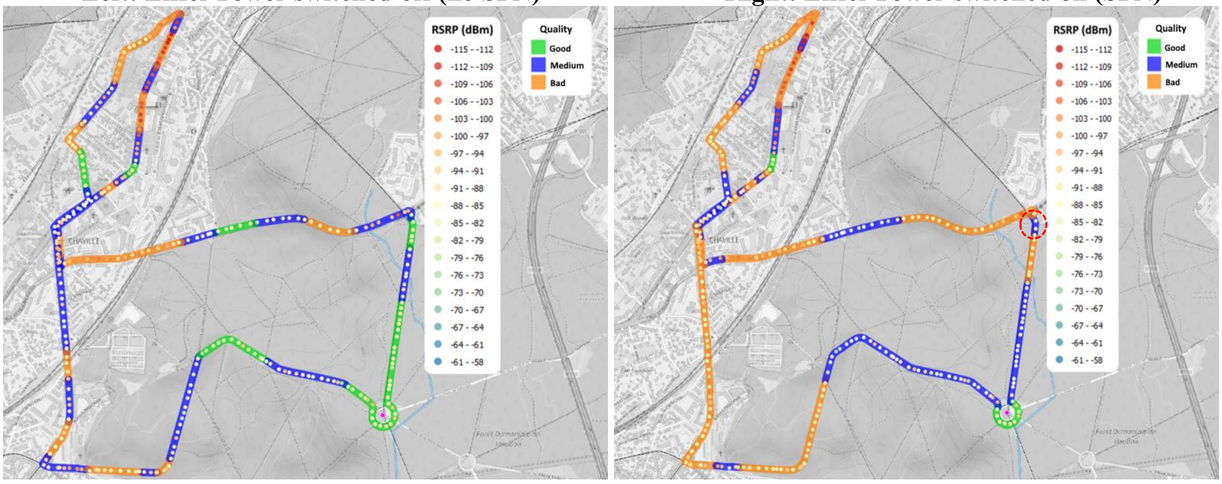
– There are however areas where the Eiffel Tower signals do not overlap the Meudon signals (mainly the northern part of the measurement route, in Chaville) and hence the perceived quality is not modified, as expected.

– The measurements available for each individual PCI show that the initial delays of both transmitters are adequately configured: for example, in the area circled with a dashed red line in Fig. 176 (right), the difference in delays (time of arrivals) between the Meudon signal and Eiffel Tower is only 12 µs, i.e. within the 16.6 µs guard interval, with a 2 dB difference of level. This confirms the correct configuration of the transmissions and should result in a correct SFN reception over the measurement route when referring to Fig. 167. This is clearly not the case here and indicates a possible area of improvement for the end-user devices that are struggling to offer a good reception in favourable SFN reception conditions, both in the short-term for the short guard interval availability induced by 3GPP Release 12 support and in the mid-term by the support of 3GPP Release 16 and above which will bring larger possible guard intervals (100 and 200 µs most notably).

FIGURE 176

Objective and subjective measurement – MCS14, Meudon area (vehicular)

Left: Eiffel Tower switched off (no SFN) Right: Eiffel Tower switched on (SFN)



11 Key findings and future work

The available measurements and feedback provide very positive results on different points:

– The experiment offered good Outdoor coverage, which was the priority for the Olympics and Paralympics Games with the ability for the users to assess the video and audio quality, in particular with live events from the games.

– The spectrum planning proved to be effective, both in terms of cohabitation with the existing DTT transmissions in the UHF band and with the exceptional PMSE high usage during the games.

– The experiment showcased a real industrial set-up on the full chain and permitted to fine tune the configuration to reach a high level of interoperability between equipment, operators and end-user devices.

– In the areas of good reception, the video (either 720p or 1080p) and audio quality of service has been really good, with a latency closer to DTT than IP streaming on the end-user devices: taking DTT as the reference, the measured delay for LTE-based 5G Broadcast was under 5s compared to the same programs on DTT, while it exceeded a minute for IP streaming. In addition, the LTE-based 5G Broadcast did not suffer from capacity limitations as happened for unicast when there was an extreme usage, such as for example during the swimming final when unicast struggled to offer a smooth experience to users in some locations while LTE-based 5G Broadcast was available and provided the end-result well ahead of unicast users.

Nevertheless, some aspects still need polishing and enhancement:

– On the coverage side, we encountered difficult reception conditions in isolated areas as well as in-car depending notably on the car characteristics (windscreen type). Portable indoor reception also remains difficult, and it was not possible to offer a consistent portable indoor coverage.

– The audio and video components of the programs sometimes suffered degradations when flipping between portrait and landscape mode, because of the change in the receiving antennas position and the occlusion from the user’s hands in landscape mode.

– There are on-going investigations to identify the reasons for some notable recurring audio impairments and/or video frame skipping: fine-tuning the entire production chain has enhanced the situation a lot but such degradations remain present and need further adjustments.

These will probably be complemented by future work in different directions:

– End-to-end optimization to reduce the current system latency to a level even closer to DTT latency (fine-tuning of the encoder and streaming configurations, BSCC settings, buffering adjustments, push vs pull mode ingestion, statistical multiplexing to improve even further the spectrum use, …).

– Test of additional services such as regional emergency warning messages, advanced video coding (VVC[16], HDR), file download, … that could not be done during the relatively short time frame around the Olympics and Paralympics Games.

– Broadcast and broadband cooperation to offer more interactivity to the end-users (return channel through unicast, complementary unicast content over WiFi, broadcast links to unicast contents such as replays, …) and a possible switching from broadcast to unicast when needed.

– Further qualification of the end-user devices (on-channel sensitivity, adjacent channel discrimination, reception thresholds, sensitivity to the receiving environment, …) as well as direct interfacing to retrieve the performance metrics from the smartphones that serve to assess the user-perceived audio and video quality.

All these efforts will need to be led in a continued partnership with the different stakeholders of the ecosystem. Support by the devices of the most recent 3GPP releases (Releases 16/17/18 and onwards) as well as the possibility to receive LTE-based 5G Broadcast signals across the whole UHF band will play a key factor in completing additional trials, optimizing the end-to-end chain and effectively deploying networks.

Annex 12

ATSC 3.0 field trial in Korea (Rep. of) : ATSC 3.0 single-frequency networks in the Seoul metropolitan area

Section 1: Mobile reliability gain of ATSC 3.0 Diversity Receiver

1 Overview

Vehicular reception of broadcast content has become essential, boosted by the increased sophistication of automobiles and the widespread use of in-vehicle media-based entertainment. ATSC 3.0 has evolved to cope with the challenging nature of high-mobility reception environments.

Vehicular environments have proven to be a challenge to TV broadcasting, where dynamic adaptation of transmission schemes is not a viable option due to the lack of a dependable feedback channel and retransmission. The physical layer of ATSC 3.0 manages the challenges of broadcast channel dynamics by offering robust modulation and expansive interleaving, which provide operability even below 0 dB signal-to-noise ratio (SNR).

[16] After the Olympics and Paralympics Games, VVC was successfully tested with the support of Ateme using a dedicated application providing support for the VVC codec on the devices (which was not the case of the insTNT application at the time of testing)

The single-frequency network (SFN) topology of the ATSC 3.0 system is regarded as another remedy against mobility-caused penalties. The SFN topology offers opportunities for transmit diversity and signal aggregation which improves signal quality at the receive end.

Field testing has shown that the real-world mobile environment remains challenging. Thus, it is likely that the conventional single-antenna system may not be satisfactory for high-speed urban vehicular scenarios. In fact, harnessing antenna diversity could effectively cope with mobile connectivity challenges.

Very high frequency (VHF) and ultra-high frequency (UHF) signals are normally used for terrestrial broadcasting in many countries. The corresponding reception system should guarantee a spacing of more than several tens of centimetres between antennas for optimized antenna diversity. For this reason, multi-antenna diversity was assumed to be physically inadequate for mobile TV reception, especially when the receiver was a handheld device such as a smartphone. In vehicular scenarios, however, the dimension of the antenna system can be extended to size of an automobile or rail-vehicle, so multiple antennas can be successfully accommodated.

Based on these considerations and tests, a vehicle-type diversity receiver (DivRx), using multiple antennas mounted on the vehicle exterior, was implemented to improve ATSC 3.0 mobile reception reliability. This improvement was tested through extensive field experiments on actual roadways. This project, whose results are described in this Annex, field tested the antenna configurations across the operating ATSC 3.0 SFN in Korea (Republic of), on a route traversing a number of cities. As per the measured results, this report presents the real-world reliability gain of DivRx by comparing the four- and two-antenna DivRx cases with single-antenna reception.

2 DivRx description

The DivRx configuration of interest was a type applying maximal-ratio combining (MRC) over the input branches, where each branch refers to a path associated with each antenna. That is, a weighted summation was applied across the signal paths, where the weighting coefficients were determined in a matched channel fashion. To this end, the channel estimates were obtained for each signal path, using reference signals within the ATSC 3.0 physical layer frames. The decoding procedures were carried out on the post-MRC signals, with the aggregation of signal branches maximizing SNR.

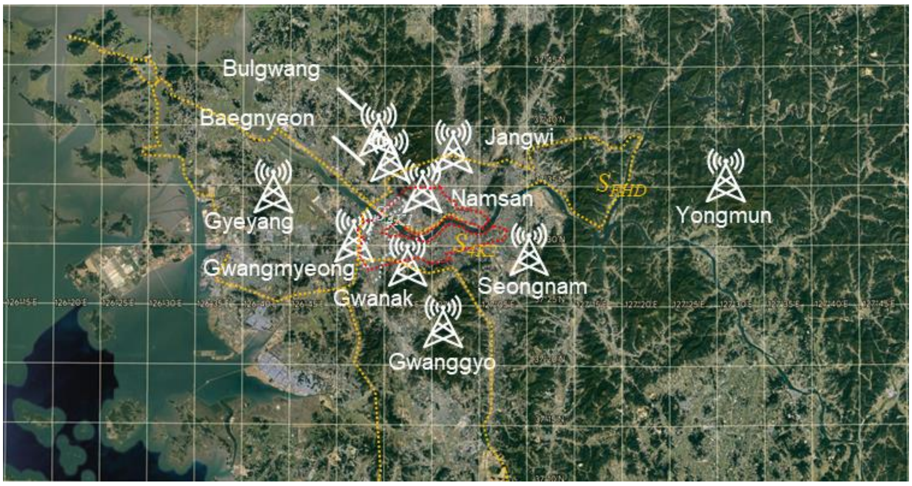
Each antenna branch was tested and evaluated for both signal acquisition and synchronization. Based on this detection result, the DivRx tests identified whether a branch signal was present or lost. If a branch signal was lost, the corresponding branch was automatically dropped from signal combining.

3 Field experiment description

The field measurements took place in the Seoul Metropolitan Area and Gyeonggi Province, Korea (Republic of). Data was collected in the operating network of KBS, which has provided ATSC 3.0 public TV services on UHF channel 56 (768 MHz). The Seoul Metropolitan SFN consisted of synchronized HPHT (High-Power High-Tower) transmissions whose ERPs (effective radiated powers) range up to 40 kW. The location of each tower site is shown in Fig. 177.

FIGURE 177

Geographic topology: Seoul Metropolitan SFN



The SFN of interest offered two commercial broadcast programs over channel 56. The physical layer configuration is specified in Table 59. A pair of a Full-HD (FHD) and an Ultra-HD (UHD) program was transmitted, whose data rates were 1.6 and 17.13 Mbit/s, respectively. Within the pipe capacity, 720p and 2160p H.265 video streams were conveyed, where the frame rates were both 60 fps. Their required SNR, at the threshold of visibility (ToV) of artifacts, amounted to 6.9 and 14.3 dB, respectively, in an additive white Gaussian noise (AWGN) channel.

Physical layer pipe (PLP) 0, the FHD service container, used an 8K FFT, with the intent of supporting mobile service. In contrast, 32K FFT modulation was applied to the PLP 1 container, given its intended usage in predominantly fixed environments. As this Annex centres on demonstrating the potential for mobile TV reception through the utilization of DivRx, the experiments were specifically directed toward capturing PLP 0.

TABLE 59

System parameters: ATSC 3.0 Physical Layer in Seoul Metropolitan SFN

Centre frequency		768 MHz	
Occupied bandwidth		5.832844 MHz	
Preamble parameters	FFT Size	8k (8,192)	
	Guard interval	222.22 us (GI6_1536)	
	Pilot pattern	*Dx* = 4	
	Signalling protection	L1-Basic/Detail Mode 1	
	# of preamble symbols	2	
	# of subframes	2	
		Subframe0 (PLP0)	Subframe1 (PLP1)
Payload OFDM parameters	FFT size	8K (8,192)	32K (32,768)
	Guard interval	222.22 us (GI6_1536)	
	# of OFDM symbols	34	38
	Pilot pattern	SP 4_2	SP 8_2
	Pilot boosting	0 dB (No Boost)	
	Frequency interleaving	On	On
	Time interval	CTI (Depth: 1024)	CTI (Depth: 512)

TABLE 59 (*end*)

Payload BICM Parameters	Outer code	5/15 LDPC (16,200 bits)	8/15 LDPC (64,800 bits)
	Inner code	BCH	
	Constellation	64 NUC	256 NUC
Data rate (Mbit/s)		1.6 (FHD)	17.13 (UHD)
Req. SNR (AWGN) (dB)		6.9	14.3

Figure 178 presents photographs of the customized test vehicle used for the field measurement. A series of ATSC 3.0 measurement platforms were installed, including three DivRx platforms integrated along with a spectrum analyser, audio/video decoder, and a Global Positioning System (GPS) receiver. Each of the three DivRxs incorporated four, two, and a single antenna, representing three different combining cases. Benchmark ATSC 3.0 Rx sets were additionally deployed to collect the reference data for sanity check. All the test equipment was integrated into a software-controlled measurement/analysis system. All measurement data was GPS-synchronized, recorded along with location and timestamp information. Monitoring reports included the received signal strength (RSS) at the reference antenna, SNR of the post-MRC signals, bit error rate (BER), and media packet error rate.

Ten receive antennas were mounted on the vehicle rooftop to incorporate three DivRx scenarios and other reference receptions simultaneously. Four-, dual-, and single-antenna Rx cases were analysed in a comparative sense. To assure equal consideration, the same condition was produced for each Rx case, whereby it guaranteed simultaneous measurements exactly along the same drive route, velocity, and every other background environment.

The antenna topology is shown in the rightmost part of the 2nd row of Fig. 178, illustrating the physical composition of each DivRx case. Isotropic antennas with 0 dBi gain were used, and a distance of more than one-half wavelength was employed between adjacent antenna units.

FIGURE 178

Measurement system description: Test vehicle

3 Field experiment results: Mobile reliability gain of ATSC 3.0 DivRx

The field examination tested mobile FHD reception over long-distance travel covering several cities. Physical-layer decoding of PLP 0 was monitored during the drive along closed loops starting from Ganghwado Island and turning back from Namyangju and Cheonan. The geographic trace, distribution of RSS, and drive speed pattern are presented in Fig. 179. The test route ranged 97 km north-south and 91 km east-west. The total mileage reached approximately 450 km.

FIGURE 179

Test Route and The Corresponding Distributions of Field Strength and Drive Speed

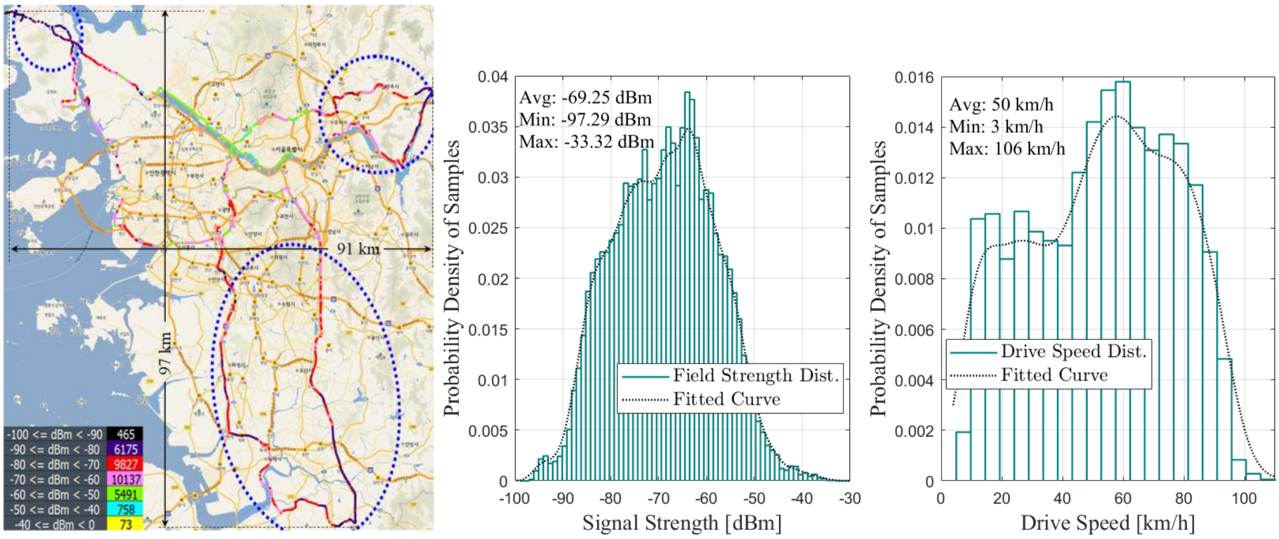


Figure 180 visualizes the signal receivability recorded throughout the test route. Whenever the signal decoding failed, the corresponding spot was marked in black, whereas the green indicator means that every received signal was successfully decoded during the corresponding unit record duration. The unit record duration was 1 s, namely, the success and failure were decided every single second.

As graphically shown, the mobile reliability improved by virtue of diversity gain. The overall percentage of successful reception in the entire route, which is referred to as *coverage rate (CR)*, was measured at 74% in the single-receiver (*SglRx*) case, whereas the dual-antenna Rx (*2DivRx*) offered a 20% increase in CR. Furthermore, the four-antenna DivRx (*4DivRx*) achieved 97% CR, which exceeds 95%, a widely-used QoS condition. [1]

FIGURE 180

Coverage Comparison: Signal Receivability over The Route (Green: Successful Decoding, Black: Signal Lost)

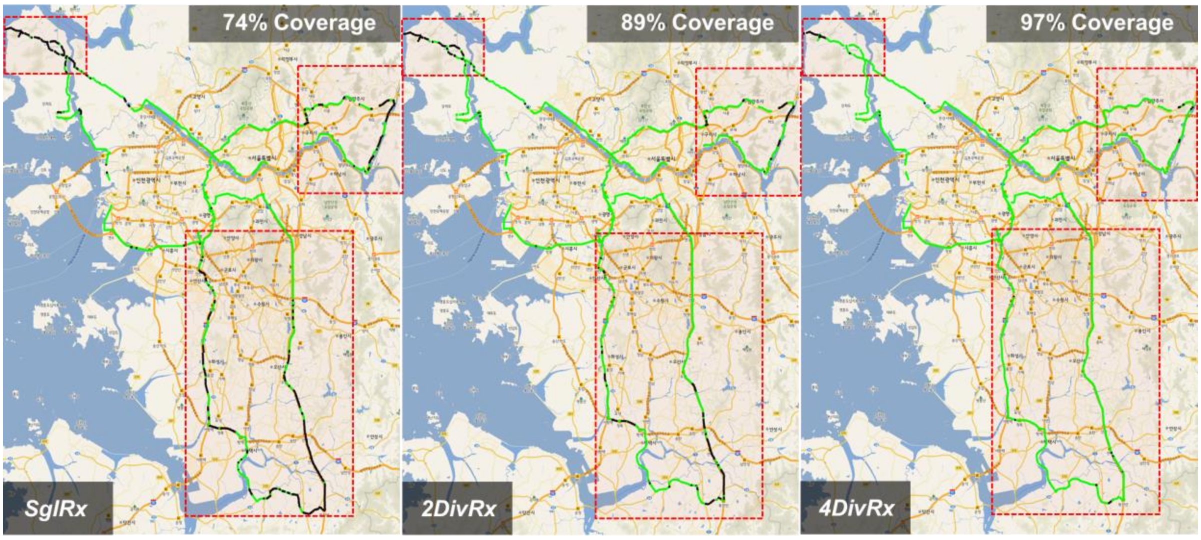
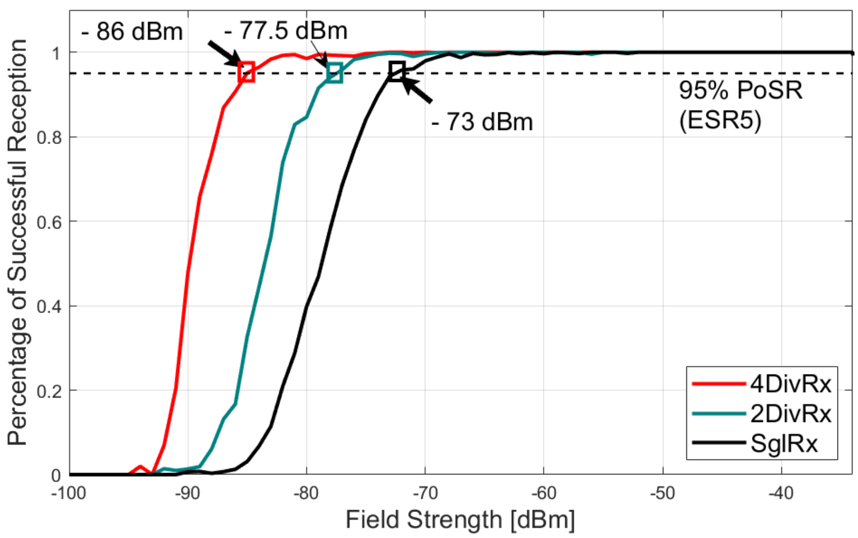


Figure 181 illustrates the percentage of successful reception (PoSR) with respect to field strength, which equivalently indicates the erroneous second rate (ESR) metric. According to Fig. 181, 4DivRx, 2DivRx, and SglRx required −86 dBm, −77.5 dBm, and −73 dBm of field strength to satisfy the ESR5 criterion, respectively.[2] The term *field strength* denotes the RSS measured at the single reference antenna leaving the signals uncombined.

This result concludes that 4DivRx and 2DivRx achieved 13 dB and 4.5 dB performance gain, respectively, over SglRx in practice, in terms of the field strength requirement under ESR5.

FIGURE 181

Mobile reliability comparison among the DivRx cases: ESR plots



4 Summary

This Section verifies that coverage gain is achievable when DivRx is deployed in vehicles, when receiving ATSC 3.0 in a broadcast SFN. Korea (Republic of) has conducted extensive field tests in Seoul and the surrounding metropolitan area within the Gyeonggi Province, by driving along a long-range route traversing multiple cities. In this effort, 4DivRx and 2DivRx were tested comparatively against the conventional SglRx. The field data demonstrate the feasibility of 4DivRx for facilitating mobile service, by showing 97% coverage rate over a test route, with the 2DivRx and SglRx alternatives achieving 89% and 74% coverage rates in the same test route, respectively. This report additionally quantified the relative reliability gain that DivRxs achieve over SglRx, in terms of the field strength required to satisfy the ESR5 criterion. The results demonstrate that the use of 4DivRx can significantly and reliably provide 13 dB of gain compared to SglRx.

Section 2: Performance of mobile multi-antenna diversity receiver using stick and patch antennas for ATSC 3.0 SFN in the Seoul metropolitan area

1 Overview

In challenging mobile environments, dynamic adaptation of transmission schemes -common in telecommunications- is not feasible due to the unidirectional nature of broadcasting. Instead, ATSC 3.0 leverages robust physical layer technologies such as strong modulation and deep interleaving to maintain reliable reception, even below 0 dB signal-to-noise ratio (SNR). In particular, the single-frequency network (SFN) architecture provides signal aggregation and transmit diversity benefits that are advantageous for moving receivers.

While field trials have shown that mobile reception remains a challenge in real-world conditions, multi-antenna diversity receiver (DivRx) has emerged as an effective solution, especially in vehicular scenarios where sufficient physical space allows for proper antenna spacing. Traditionally, stick-type antennas (S-Ant) mounted on vehicles have been used for such diversity configurations, offering high gain and omni-directional reception. However, these antennas protrude from the vehicle, potentially impacting aesthetics, aerodynamics, and durability.

An alternative approach involves the use of patch-type antennas (P-Ant), which are compact and integrable into vehicle windows or interiors. While these offer advantages in terms of form factor and vehicle integration, their diversity gain potential in mobile broadcast reception environments had not been extensively validated.

This section evaluates and compares the mobile reception performance of stick-type and patch-type multi-antenna DivRx configurations under driving conditions across the Seoul Metropolitan ATSC 3.0 SFN. Both antenna types were tested in four-antenna configurations, and their reliability was measured in terms of signal availability and reception success rate over urban and suburban drive routes.

The findings in this test provide a real-world performance comparison, demonstrating the effectiveness and trade-offs of antenna types in vehicular multi-antenna reception scenarios.

2 DivRx description

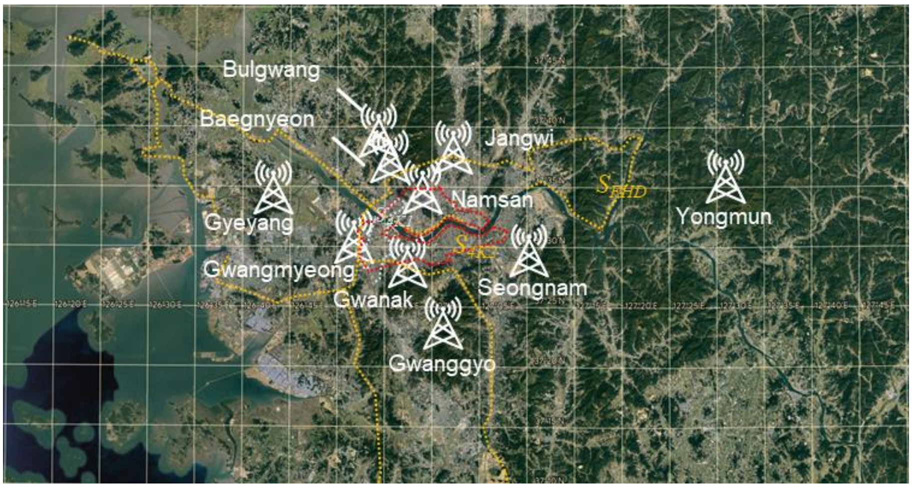
As in Part 1 section 2 above, the DivRx configuration was a type applying maximal-ratio combining (MRC) over the input branches, where each branch refers to a path associated with each antenna.

3 Field experiment description

The field trial was carried out across the Seoul Metropolitan Area and Gyeonggi Province in the Republic of Korea. Data was collected from the currently operating ATSC 3.0 network of KBS, which provides public TV services over UHF channel 56 (768 MHz). The Seoul Metropolitan SFN comprises synchronized HPHT (High-Power High-Tower) transmitters, with ERPs (effective radiated powers) reaching up to 40 kW. The geographical locations of the tower sites comprising this SFN are shown in Fig. 182.

FIGURE 182

Geographic topology: Seoul Metropolitan SFN



The physical layer configuration of this SFN transmission is detailed in Table 60. The transmission system is structured with two subframes, each conveying a separate physical layer pipe (PLP): PLP 0 and PLP 1. The respective data rates for PLP 0 and PLP 1 were 2.82 Mbit/s and 17.09 Mbit/s. The required SNRs to meet the threshold of visibility (ToV) for PLP 0 and PLP 1 were 9.29 dB and 14.3 dB, respectively, under an additive white Gaussian noise (AWGN) channel.

PLP 0, which is intended for mobile service, employed an 8K FFT mode, while PLP 1, designed primarily for fixed reception, used a 32K FFT configuration. As this contribution centres on evaluating and comparing the mobile reception performance of multi-antenna DivRx using patch-type transparent antennas and stick-type magnetic antennas in vehicular environments, the measurements were specifically directed toward capturing PLP 0.

TABLE 60

System Parameters: ATSC 3.0 Physical Layer in Seoul Metropolitan SFN

Centre frequency		768 MHz
Occupied bandwidth		5.832844 MHz
Preamble parameters	FFT size	8k (8,192)
	Guard interval	222.22 us (GI6_1536)
	Pilot pattern	*Dx* = 4
	Signalling protection	L1-Basic/Detail Mode 1
	# of preamble symbols	2
	# of subframes	2

TABLE 60 (*end*)

		Subframe0 (PLP0)	Subframe1 (PLP1)
Payload OFDM parameters	FFT size	8K (8,192)	32K (32,768)
	Guard interval	222.22 us (GI6_1536)	
	# of OFDM symbols	46	32
	Pilot pattern	SP 4_2	SP 8_2
	Pilot boosting	0 dB (No boost)	
	Frequency interleaving	On	On
	Time Intlv	CTI (Depth: 512)	CTI (Depth: 1024)
Payload BICM parameters	Outer code	6/15 LDPC (16 200 bits)	9/15 LDPC (64 800 bits)
	Inner code	BCH	
	Constellation	64 NUC	256 NUC
Data rate		2.82 Mbit/s (FHD)	17.09 Mbit/s (UHD)
Req. SNR (AWGN)		9.29 dB	16.82 dB

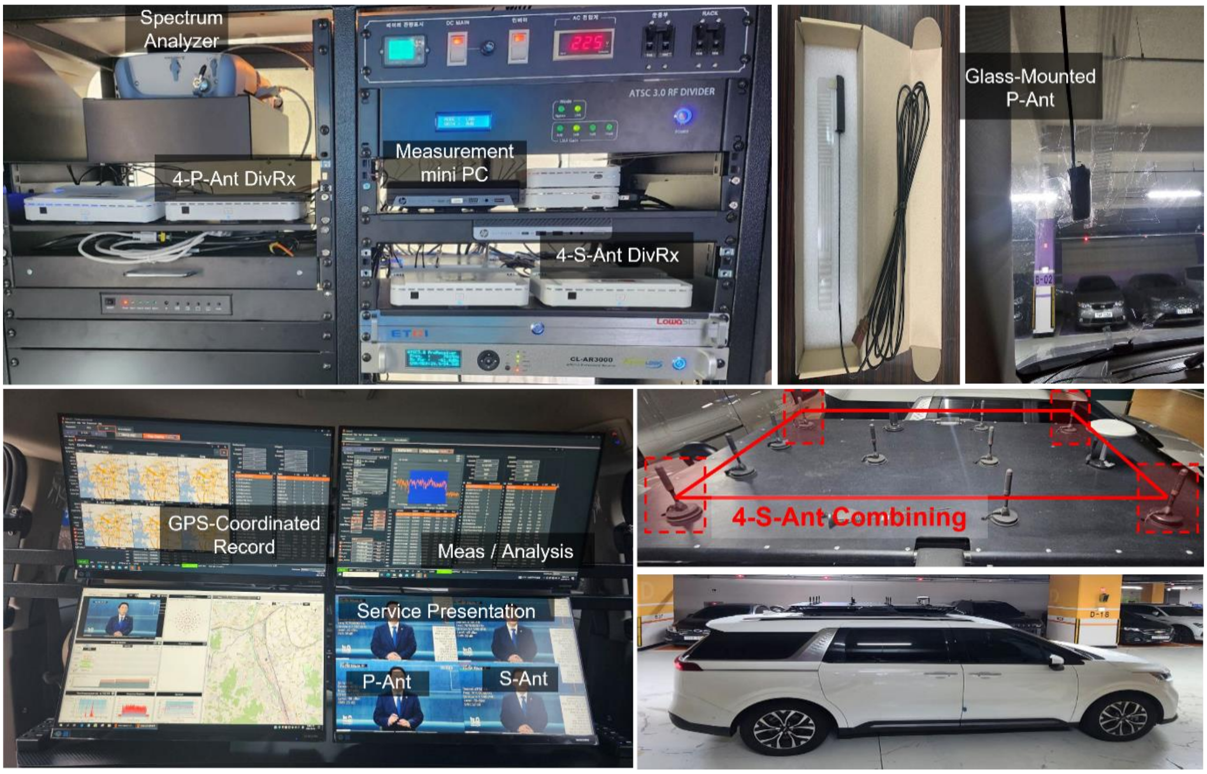
Figure 183 illustrates the customized test vehicle employed for the field measurements. The vehicle was equipped with a suite of ATSC 3.0 measurement systems, which comprised two DivRx platforms, a spectrum analyser, an audio/video decoder, and a Global Positioning System (GPS) receiver. Each DivRx platform was configured with four antennas: one system employed S-Ant mounted on the vehicle rooftop, while the other utilized P-Ant affixed to the interior surface of the vehicle windows. All instrumentation was orchestrated through a software-driven measurement and analysis framework. Data acquisition was GPS-synchronized, ensuring precise logging of positional and temporal metadata. The monitoring outputs encompassed received signal strength (RSS) from a reference antenna, SNR of the post-MRC signals, bit error rate (BER), and media packet error rate.

To ensure a fair comparison, the configuration was carefully designed such that each receiver operated under identical diversity conditions, with simultaneous measurements conducted along the same drive route, speed, and environmental background – thereby enabling a controlled evaluation of reception performance that isolates the effect of antenna type.

The P-Ants are shown in the rightmost part of the first row of Fig. 183. A total of four patch-type antennas were employed, with two units vertically affixed to the inner surface of the front windshield and the remaining two mounted in the same manner on the rear windshield of the test vehicle. The topology of the four S-Ants is illustrated in the rightmost image of the second row in Fig. 183. The antennas employed in this configuration were isotropic in pattern, with each S-Ant offering a gain of 3 dBi. In contrast, each P-Ant featured a gain of 1.5 dBi. To ensure effective spatial diversity, the spacing between adjacent antenna elements was maintained at greater than one half-wavelength.

FIGURE 183

Measurement system description: Test vehicle



4 Field experiment results: Comparative mobile reception performance of ATSC 3.0 DivRx using S-Ant and P-Ant

The field examination was conducted to assess mobile reception performance across an extended drive route traversing multiple urban and suburban areas. During the test runs, real-time monitoring of physical-layer decoding was focused on PLP 0, with measurement activities executed along closed-loop circuits originating from Ganghwado Island and returning from the vicinities of Namyangju and Cheonan. Fig. 184 depicts the recorded travel trajectory, along with the spatial distribution of RSS and the corresponding drive speed profile. The drive path ranged approximately 97 km in the north–south direction and 91 km east–west, resulting in a cumulative test mileage of nearly 450 km.

Figure 184 provides a visualization of signal receivability recorded across the entire test route. Whenever the signal decoding failed, the corresponding spot was marked in black, whereas the green indicator means that every received signal was successfully decoded during the corresponding unit record duration. The unit record duration was 1 sec., namely, the success and failure were decided every single second.

The left-hand map illustrates the performance of the S-Ant-based DivRx system, which achieved a coverage rate (CR) of 95.45% over the full route. The CR refers to the overall percentage of successful reception across the entire test path. In contrast, the right-hand map corresponds to the P-Ant configuration, which yielded CR of 78.34% under the same drive conditions.

FIGURE 184

Test route and the corresponding distributions of field strength and drive speed

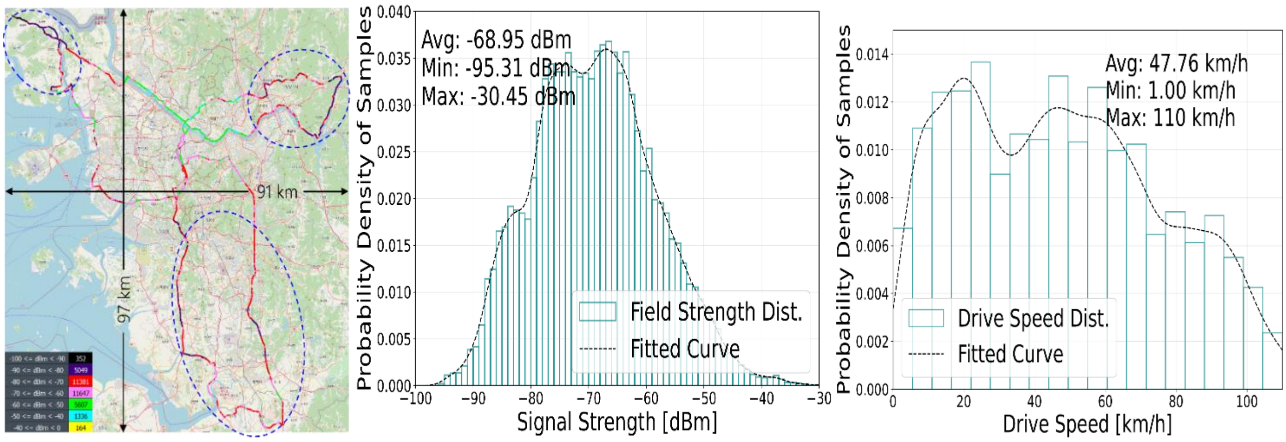


FIGURE 185

Coverage comparison: Signal receivability over the route (Green: Successful decoding, Black: Signal lost)

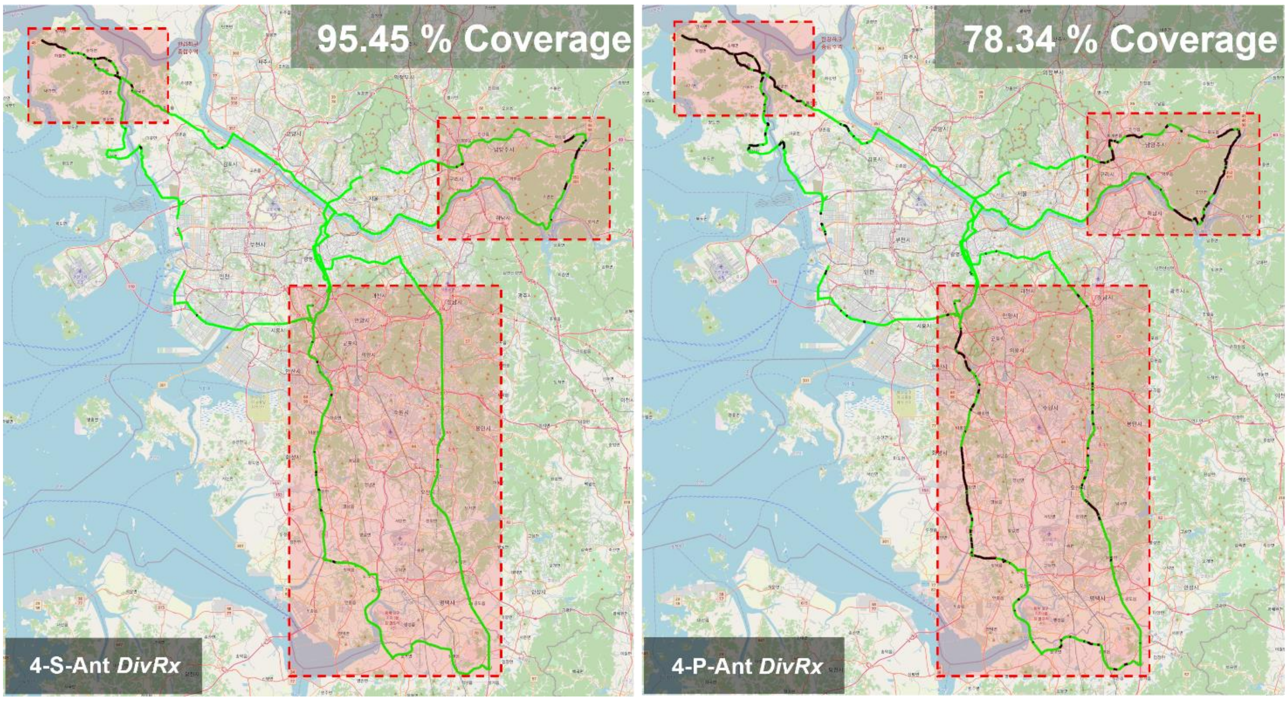
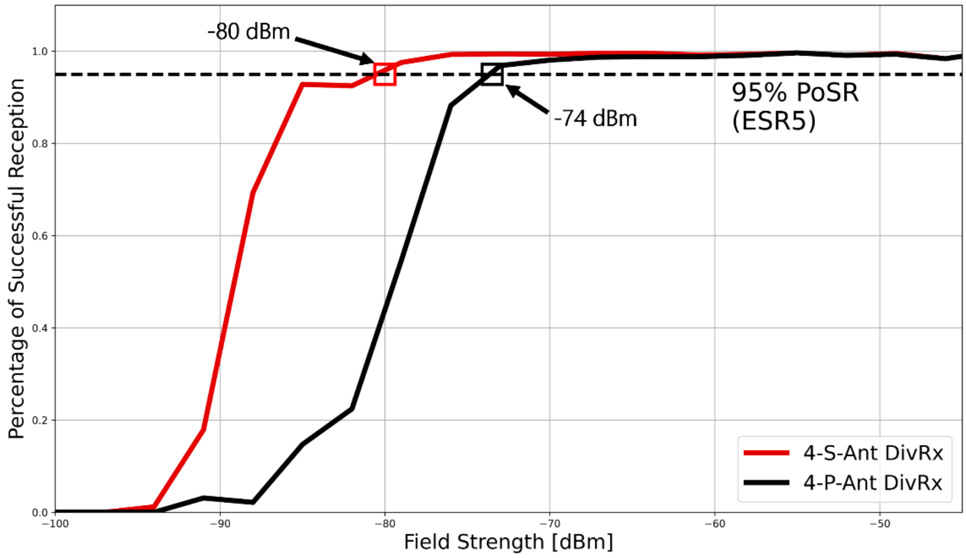


Figure 186 presents the percentage of successful reception (PoSR) as a function of field strength for the 4-S-Ant and 4-P-Ant DivRx configurations. The 4-S-Ant system meets the 95% PoSR threshold, known as ESR5, indicating a condition where the erroneous second rate remains below 5%, at a field strength of −80 dBm, while the 4-P-Ant configuration requires −74 dBm to achieve the same performance level. This corresponds to a 6 dB reliability gain in favor of the stick-type implementation under low signal conditions. The term *field strength* denotes the received signal strength (RSS) measured at a single reference antenna, with no signal combining applied.

FIGURE 186

Mobile reliability comparison between 4-S-Ant and 4-P-Ant DivRx configurations: ESR plots



5 Summary

This section presents a comparative field evaluation of mobile reception performance using two multi-antenna DivRx configurations -one employing rooftop-mounted S-Ant and the other using glass-mounted P-Ant- under the ATSC 3.0 SFN operating in the Seoul Metropolitan Area.

Field trials conducted along a 450 km closed-loop drive route demonstrated that the 4-S-Ant configuration achieved a higher CR (95.45%) and required a lower field strength (−80 dBm) to meet the ESR5 threshold, compared to the 4-P-Ant configuration (78.34% CR and −74 dBm ESR5 threshold). These results suggest that, under weak signal conditions, the S-Ant configuration offers approximately 6 dB better reception sensitivity relative to the P-Ant configuration.

The relatively poorer performance of the P-Ant system can be attributed to environmental and structural factors inherent to its integration. Glass-mounted antennas may experience signal attenuation due to their proximity to the vehicle body, as well as potential interference from defrosting wires or window films. In addition, the mounting of antennas inside the vehicle may lead to additional losses caused by reflection, penetration loss, and diffraction as radio waves interact with the windshield glass and interior materials. These factors can collectively reduce the effective signal power reaching the antenna, especially in high-frequency UHF bands. Furthermore, the interior positioning may result in reduced exposure to incident broadcast signals in obstructed environments, such as urban canyons or hilly terrain.

Nevertheless, the P-Ant system exhibited stable decoding performance across most of the drive route and provides several practical advantages, including compact form factor, design-friendly integration, and resistance to external environmental effects such as wind, moisture, and physical impact. These attributes make the P-Ant configuration a viable and attractive solution for real-world automotive applications – especially in use cases where externally mounted antennas are restricted by vehicle styling, structural limitations, or manufacturing considerations. When supported by robust receiver algorithms, the slightly reduced reception sensitivity of the P-Ant system remains well within acceptable operational thresholds for many commercial and consumer deployment scenarios.

References

[1] Report ITU-R BT.2215-7 – Measurements of protection ratios and overload thresholds for broadcast TV receivers

[2] Report ITU-R BT.2386-5 – Digital terrestrial broadcasting: Design and implementation of single frequency networks (SFN)

[3] ATSC Recommended Practice A/327:2023-03: Guidelines for the Physical Layer Protocol